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Sprayed Asbestos-Containing Materials in Buildings A Guidance Document

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GUIDELINE SERIES

SPRAYED ASBESTOS-CONTAINING MATERIALS IN BUILDINGS:
A Guidance Document

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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This guidance document summarizes the available information on sprayed asbestos-containing materials in buildings. It describes actions that may be taken when a building owner knows or suspects that friable asbestos materials are present. Application of sealant coats and removal of asbestos materials are discussed.

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A Guidance Document

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ABSTRACT

The recognition of the potential health hazards from exposure to asbestos fiber and the increasing use of this mineral in many products over the past several decades has prompted the U.S. Environmental Protection Agency and other federal agencies to enact regulations for its safe handling to protect the public, the environment and the worker. This document is prepared for those involved in the use, removal, and disposal of asbestos materials in the building trades.

Asbestos in all its forms is considered a serious respiratory hazard. Individual fibers are invisible to the naked eye and their small size gives them prolonged buoyancy even in still air. Unlike most chemical carcinogens, the mineral fibers persist in the environment almost indefinitely and, when present in a building space open to its occupants, represent a continuous source of exposure. From a toxicological perspective, the latency period before onset of clinical signs is typically decades leading to a difficulty in linking cause and effect. Since the beginning of the century, asbestos has been used as a major constituent or an important additive to many consumer products so that there are many sources of exposure to the general public. In the past few tens of years several asbestos products have been sprayed on structural steel for fireproofing or have been sprayed as decorative coatings on ceilings.

With a view toward controlling exposures to the public, guidelines are presented for the detection and monitoring, removal or encapsulation, and disposal of asbestos-containing building materials. Measures available to protect workers and building occupants are presented based on field measurements and theoretical considerations. Sampling procedures are discussed so that the user of this document can take an active role in determining whether protective action is needed and, if so, how best to protect himself, the public, and the environment.

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PART I

ASBESTOS: BACKGROUND, ENVIRONMENTAL CONTAMINATION, STANDARDS, AND ANALYSIS

1. INTRODUCTION

1.1 NATURE OF ASBESTOS

In recent years, there has been an increasing awareness of the importance of environmental factors in carcinogenesis. Asbestos has become a widespread environmental contaminant for large segments of our society, and has caused fibrosis and malignancies of the lung and other organs. The mineral fibers resist degradation, and persist in the environment. Because of fibrous form and small size they possess the aerodynamic capability of prolonged suspension in air and repeated cycles of reentrainment. Asbestos fibers, even in low concentration, may have carcinogenic potential, and a biologic activity that may persist for the lifetime of an exposed host.

Asbestos is a generic term applied to a wide chemical variety of naturally occurring mineral silicates which are separable into fibers. The six major recognized species of asbestos minerals are chrysotile of the serpentine group ("white asbestos"); and cummingtonite-grunerite asbestos (also amosite or "brown asbestos"), crocidolite ("blue"), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos of the amphibole group. Specific attributes and characteristics vary with the different types, but the commercially valuable asbestos minerals, in general, form fibers which are incombustible, possess high tensile strength, good thermal and electrical insulating properties, and moderate to good chemical resistance. They may be packed, woven, or sprayed. These characteristics of durability, flexibility, strength, and resistance to wear make asbestos well-suited for an estimated 3,000 separate commercial, public, and industrial applications.[1] These include roofing and flooring products; fireproofing textiles; friction products; reinforcing material in cement, pipes, sheets, and coating materials; and thermal and acoustical insulations. Asbestos has widespread application in all industrial societies and is a nearly indispensable and ubiquitous material.[2-4]

Historically, asbestos remained a curiosity for centuries, with negligible production until the beginning of the 20th century when it was used as thermal insulation for steam engines. Worldwide production of the mineral now approaches 5 million tons annually, with chrysotile the principal fiber type.[5] Annual United States consumption is approximately 900,000 tons, with more than 70 percent used in the construction industry.

It has been estimated that a majority (85 to 92 percent) of end-product uses have effectively immobilized the asbestos fibers by mixing them into a strong binding material; e.g., cement.[6] Fibers are still liberated, however, during fabricating operations such as grinding, milling or cutting. The remaining 8 to 15 percent is in a form that will more readily permit fiber dissemination, such as friable insulation material or bagged fibers for mixing.

1.2 SPRAY APPLICATION OF ASBESTOS

Of the many uses of asbestos, the technique of spraying fibers onto structural surfaces has been perhaps the most significant in causing asbestos exposure to construction workers during application and to the general population thereafter. Such material, in loosely bonded friable form, has been applied extensively to steelwork to retard structural collapse during fire, and to overhead surfaces for purposes of acoustic and thermal insulation, decoration, and condensation control.

Spray application of asbestos fireproofing and insulating material began in England in 1932. Spray application offered the advantage of rapidly covering large or irregular surfaces evenly and efficiently without the use of mechanical support or extensive surface preparation. Early spray applications in the U.S. were mainly for decorative use and acoustical insulation in ceiling material in clubs and restaurants. In 1950 more than half of all multistory buildings constructed in the U.S. used some form of sprayed mineral fiber fireproofing.[7] In 1968 fireproofing alone accounted for 40,000 tons of sprayed material.[8]

The health hazards of spray application of asbestos to spray operators, other construction workers, and the general public in the vicinity of such operations were recognized and documented.[9] Because of these hazards, the New York City Council banned spray application in 1972.[10] Other cities and states followed suit, and in 1973 the U.S. Environmental Protection Agency (EPA) banned spray application of insulating or fireproofing material containing more than 1 percent asbestos by weight.[11] Decorative materials were not included in the ban, and this omission permitted some continuing application. One example involved all overhead surfaces in the large (1200 unit) condominium complex using a friable mixture of 30 percent asbestos.[12]

On March 2, 1977, EPA proposed an amendment to the national emission standard for asbestos.[13] These amendments would extend the spraying restrictions to all materials which contain more than 1 percent asbestos by weight.

Numerous substitutes for sprayed asbestos materials are currently available.[14] Most spray materials currently in use contain fibrous glass or nonasbestos mineral fibers along with cement, gypsum, or other binders similar to those used for asbestos. These materials can be used for fireproofing, thermal and acoustical insulation, and decoration.

The possible carcinogenicity of replacement materials, especially fibrous glass, is under investigation. The physical dimensions of glass fibers are much larger than asbestos fibers, and currently there is no epidemiologic study demonstrating carcinogenicity of this product. Recent experimental work has indicated carcinogenic potential of fibrous glass with dimensions reduced to approximately the size of asbestos fiber,[15] and similar findings with other minerals may occur in the future.

1.3 POTENTIAL FOR ENVIRONMENTAL CONTAMINATION

Environmental contamination from asbestos-containing surfaces can occur not only during construction and demolition, but also throughout the life of the structure. Frequently these surfaces are exposed or accessible (see Figure I-1-1). They can include open and visible sprayed ceilings, walls, or structural members, or surfaces hidden by suspended ceiling systems accessible to maintenance personnel.

The proportion by weight of asbestos in asbestos-containing material found in sprayed ceilings or overhead surfaces is generally in the 10 to 30 percent range but may vary from essentially none to nearly 100 percent.[16] The remainder may be fibrous glass, various other fibers, and adhesives. As in other uses, chrysotile asbestos is the most common fiber type.

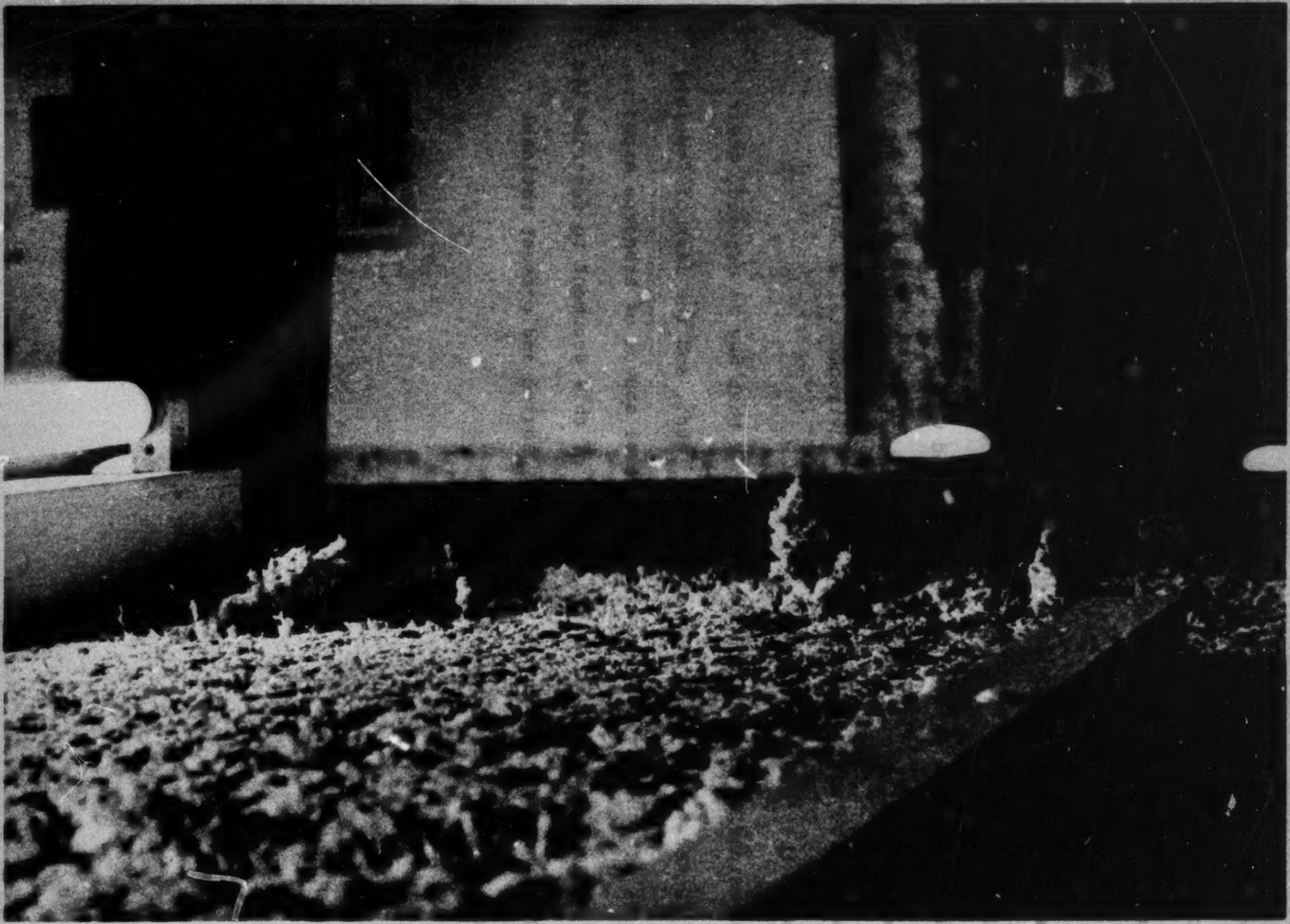

Figure I-1-1. Friable asbestos-containing material hanging from damaged ceilings.

Although the spraying of friable asbestos-containing materials in construction has all but ceased, sprayed material within existing structures remains a potential widespread source of asbestos fiber exposure. Although exact figures are not available, if it is assumed that spray application was a common practice from 1958 to 1973, and that fireproofing was the major use of this material, a conservative order-of-magnitude estimate of the total amount of asbestos sprayed over this period would be 500,000 tons. It is indeed possible, therefore that sprayed asbestos material within buildings may become the most significant source of environmental asbestos contamination in the future.

Considering the large number of people that may be exposed, their range in age and habits, such as smoking, etc., and the lack of feasible means of personal protection, this potential source of asbestos exposure could be significant. It is the purpose of this document to describe the potential hazards to the public from this source and present rational alternatives for its control.

2. ASBESTOS CONTAMINATION OF THE ENVIRONMENT

2.1 ASBESTOS FIBER SIZE AND AMBIENT COMMUNITY CONTAMINATION

During mining, milling, bagging, or spraying, the processing and disturbance of asbestiform minerals can result in the release of fibers and fiber bundles into the environment. Asbestos fibers, resistant to degradation by thermal or chemical means, also remain available for release into the environment from any source, especially from loosely-bound asbestos-containing materials. As shown in Figure I-2-1, dispersed asbestos fibers have a length range from less than 0.1 micrometers (μm) to some tens of micrometers. This size range of asbestos fibers points out two significant attributes: aerodynamic capability and respirability. The fibers can become suspended in air, and thus are available for respiration, and retention in the lung. The fibers may also enter the gastrointestinal tract directly and via the lung clearance mechanism.

Studies of urban ambient air using electron microscopy have shown that asbestos concentration levels are generally below 10 ng/m^3, and rarely exceed 100 ng/m^3.[*] Mean asbestos levels in 49 United States cities were

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[*] In this document, asbestos concentrations are expressed as a specific weight; (i.e., nanograms per cubic meter) when determined by electron microscopy; and as the number of fibers per cubic centimeter (f/cm^3) when measured by phase contrast microscopy. Depending upon the laboratory, results of asbestos analyses by electron microscopy may be reported on a weight basis, as the number of fibers present, or both (see footnote on page I-4-7).

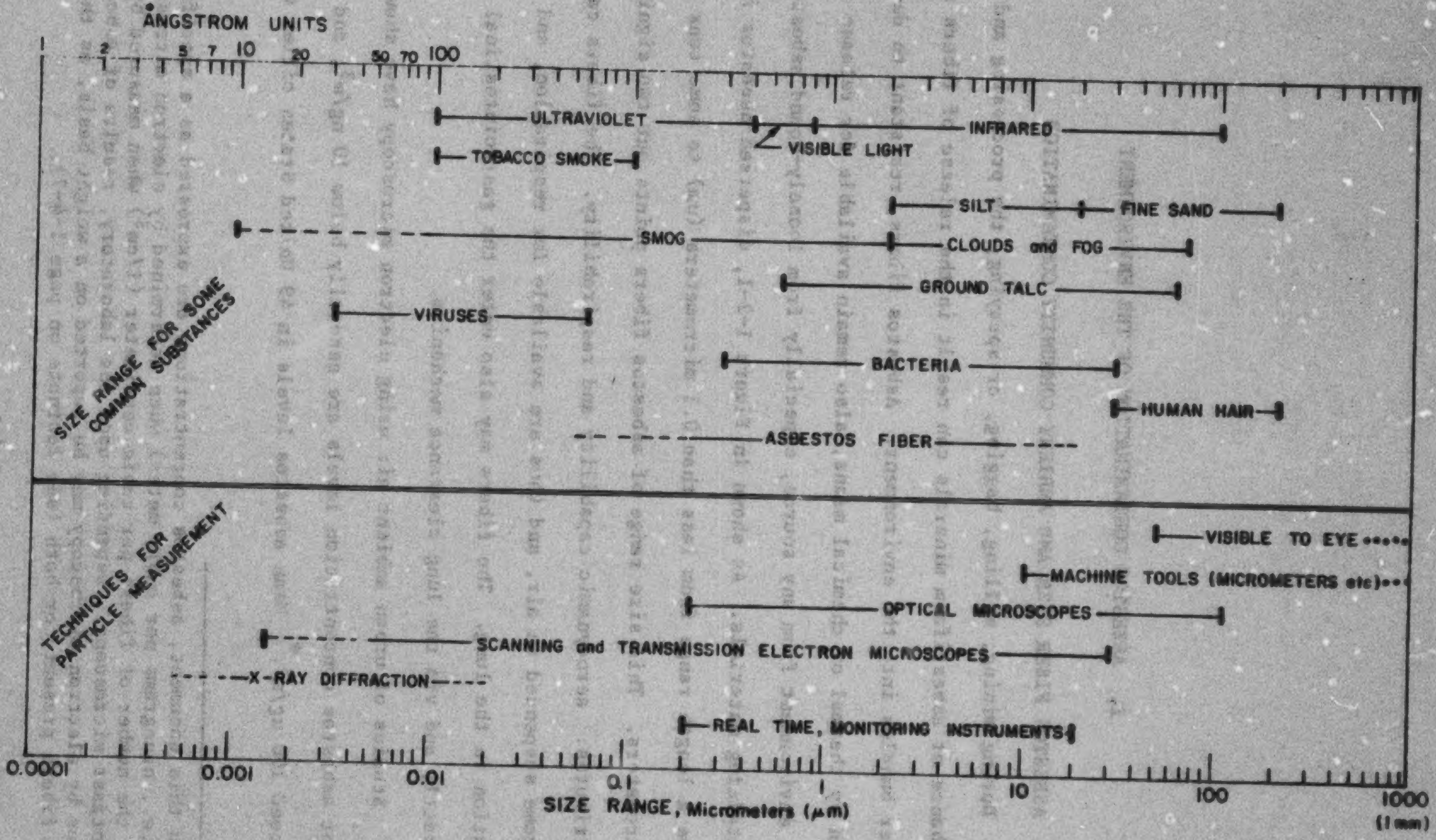


Figure I-2-1. Asbestos size comparison with other particles and measurement techniques.

found to be 4.3 ng/m^3 in 1969, and 2.1 ng/m^3 in 1970. Higher urban readings occurred in communities with asbestos emission sources such as factories and near construction sites where asbestos spraying was in progress. A level of 0.1 ng/m^3 was found in a single nonurban sample.[9,17-19]

2.2 ASBESTOS FIBER AERODYNAMICS

An asbestos fiber, once released into the air by any means, will enter a phase of downward settling determined in general by its mass, form, and axis attitude. The range of these fiber characteristics strongly affects settling velocities and hazard potential since those fibers able to remain aloft for many hours have a higher exposure probability than rapidly-settling fibers. Settling velocity is strongly dependent upon fiber diameter and to a lesser extent upon fiber length. Figure I-2-2 shows the theoretical settling velocities in still air for fibers of varying size, alignment, and aspect ratio. Note the tendency for a roughly twofold settling between horizontal and vertical fibers. The mathematical derivation of this graph is presented in Appendix B.

The theoretical settling curve data presented in Figure I-2-2 are in close agreement with actual settling data obtained under working conditions.[20] By way of example, fibers 1 to 5 μm in length with an aspect ratio (length divided by width) of roughly 5:1 would be common in material dispersed from overhead insulation in buildings. The settling velocities for fibers 5, 2, and 1 μm in length with a 5:1 aspect ratio and with an axis attitude varying between vertical and horizontal, would be 2×10^{-2}, 4×10^{-3}, and 10^{-3}, respectively. The theoretical times needed for such fibers to settle from a 3 meter (9 ft) ceiling are 4, 20, and 80 hours in still air. Turbulence will prolong the settling and also cause reentrainment of fallen fibers.

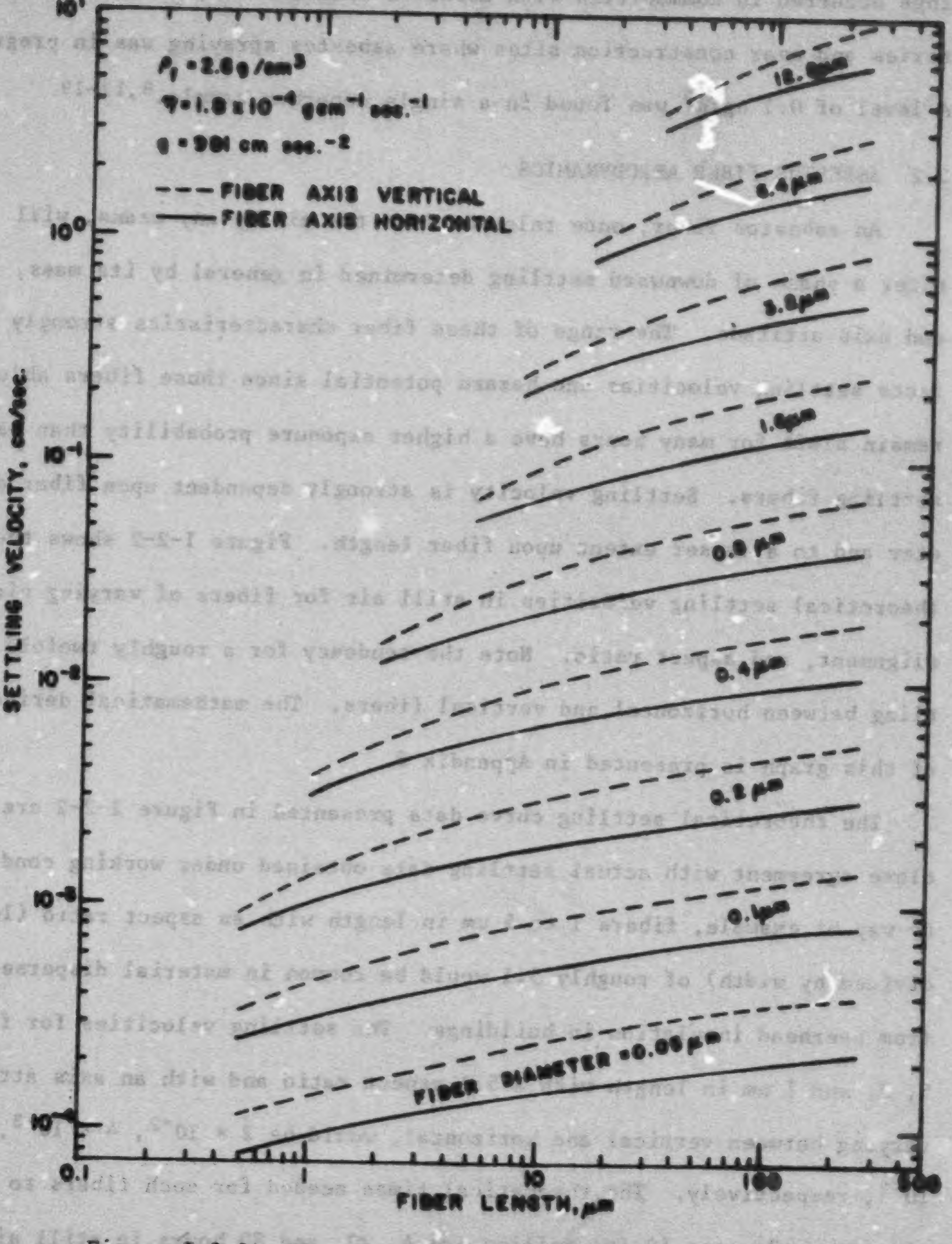


Figure I-2-2. Theoretical settling velocities of fibers.

During the time that the fiber remains airborne, it is able to move laterally with air currents and contaminate spaces distant from the point of release. Significant levels of contamination have been documented hundreds of meters from a point source of asbestos fibers,[9] and fibers may also move across contamination barrier systems with the passage of workers during removal of material.[19]

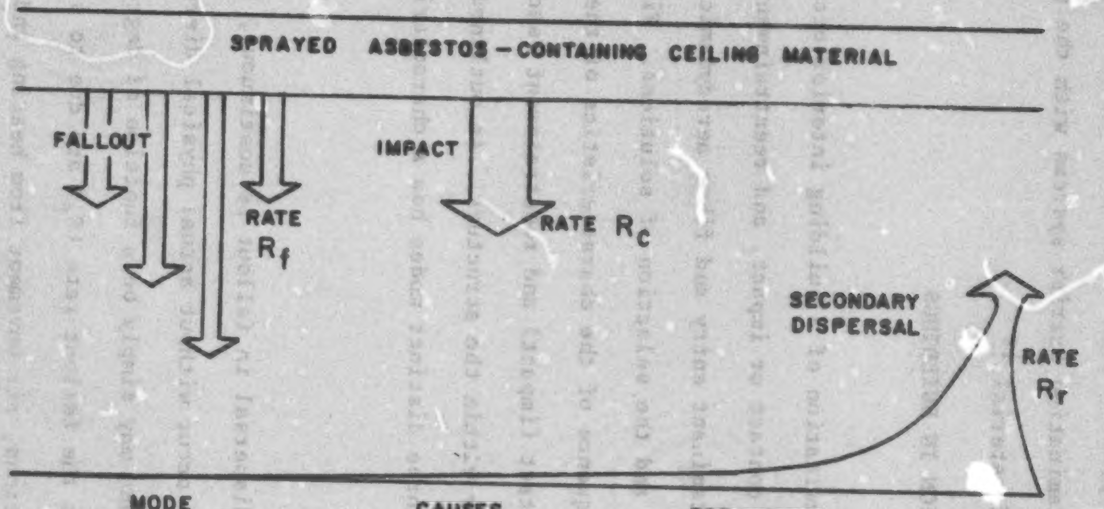
2.3 ASBESTOS CONTAMINATION IN BUILDINGS

2.3.1 Basic Concepts

Asbestos fiber contamination of a building interior occurs by three general modes: fallout, contact or impact, and reentrainment. Consideration of each mode of contaminant entry and fiber aerodynamics is useful in exposure risk evaluation and the selection of solutions. Fiber fallout is in great part a consequence of the characteristics of the ceiling material itself, while contact (impact) and reentrainment (secondary dispersal) result from activity within the structure. As outlined in Figure I-2-3, each of the three distinct modes has a characteristic rate of fiber dispersal.

Fallout

The rate of fiber dispersal in fallout is continuous, low level and long lived. Fallout may occur without actual physical disruption of the fiber-bearing material and may simply be a function of degradation of the adhesive. Variations in the fallout rate (R_f) are due to structure vibration, humidity variations, air movement from heating and ventilating equipment, and air turbulence and vibration caused by human activity. This rate may also gradually increase due to aging of the adhesive component of the materials ranging from nearly zero for cementitious mixes in good repair to roughly 100 ng/m^3 for deteriorating dry mix applications.


SPRAYED ASBESTOS – CONTAINING CEILING MATERIAL
FALLOUT
RATE R_f
IMPACT
RATE R_C
SECONDARY DISPERSAL
RATE R_r

MODE	CAUSES	FREQUENCY	RATE
FALLOUT	AIR MOVEMENT VIBRATION	CONSTANT	LOW (R_f)
IMPACT	MAINTENANCE ACCIDENTAL IMPACT	OCCASIONAL	HIGH (R_C)
SECONDARY DISPERSAL	USUAL ACTIVITY CUSTODIAL SERVICE	FREQUENT	LOW TO HIGH (R_r)

Figure I-2-3. Modes and rates of fiber dispersal.

Contact

Friable sprayed asbestos surfaces have low impact resistance and are easily damaged. Even minor physical contact can result in fiber release into the environment. Such contact may be intentional and unavoidable during maintenance activities, accidental during routine activity, or deliberate through vandalism. Contact contamination depends rather simply upon accessibility and the probability of contact, the function of the structure, and the activities of the users.

The contact mode of fiber dispersal produces the highest release rates (R_c). The fiber contamination level during even routine maintenance and repair activities may exceed 20 f/cm^3, and removal of dry sprayed asbestos material can yield fiber contaminations of over 100 f/cm^3.[20]

Reentrainment

The reentrainment of fibers that have already fallen onto interior surfaces repeatedly causes contamination of the environment, as disturbance of these settled fibers causes resuspension in the atmosphere (R_r). A fiber released from an overhead sprayed surface may participate in repeated cycles of resuspension and settling.

It is possible to have fiber counts as high as 5.0 f/cm^3 in activities such as custodial work. These custodial activities may result in significant levels of contamination and give rise to significant exposures. In a university library with a deteriorating sprayed asbestos ceiling, custodians were continuously dusting over a mile of shelving and generating an average of 4.0 f/cm^3 contamination level for themselves and 0.3 f/cm^3 for nearby library users.[20]

2.3.2 Airborne Asbestos Concentrations

Table I-2-1 presents data from studies on asbestos contamination in buildings. Consistent with the basic concepts outlined above, under quiet conditions contamination levels are low; under conditions of general activity an increase is seen; and contact and reentrainment create relatively high contamination levels. If friable sprayed surfaces are disturbed or damaged for any reason, fibers are released into the environment. Even the machining or cutting of cementitious asbestos, for example, can release fibers in excess of the OSHA ceiling limit of 10 f/cm^3.[16]

Exposure probabilities for both workers and building users can be estimated to some degree by consideration of the three modes of contamination and the general activity within the building. Quiet activity refers to background conditions within a structure or it may represent the usual activity level in an area with low probability of either contact or reentrainment of asbestos. Under these conditions contamination levels may approach the fallout rate and be negligible. For buildings with deteriorating asbestos material, however, quiet activity contamination levels may be significantly higher than outdoor ambient air levels. Studies that have included quiet activity condition testing have found levels from near the ambient background to approximately 100 ng/m^3 by electron microscopy,[18] and 0.02 f/cm^3 by optical microscopy.[20] Determination of asbestos contamination levels during periods of quiet activity conditions are extremely misleading in the estimation of actual exposure since only fallout or similarly low rates are seen.[20]

Routine activities in a structure containing sprayed asbestos surfaces will usually result in elevated fiber levels. Although statistically

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Table I-2-1. AIRBORNE ASBESTOS IN BUILDINGS

Sampling conditions or situation	Mean counts (f/cm^3)	Number of samples	Standard deviation
1. University dormitory, UCLA[21] Exposed friable surfaces, 98% amosite General student activities	0.1	–	0 to 0.8 (range)
2. Art and Architecture Building, Yale University.[20] Exposed friable ceilings, 20% chrysotile			
Ambient air, City of New Haven	0.00	12	0.00
Fallout			
Quiet conditions	0.02	15	0.02
Contact			
Cleaning, moving books in stack area	15.5	3	6.7
Relamping light fixtures	1.4	2	0.1
Removing ceiling section	17.7	3	8.2
Installing track light	7.7	6	2.9
Installing hanging lights	1.1	5	0.8
Installing partition	3.1	4	1.1
Reentrainment			
Custodians sweeping, dry	1.6	5	0.7
Dusting, dry	4.0	6	1.3
Proximal to cleaning (bystander exposure)	0.3	–	0.3
General Activity	0.2	36	0.1
3. Office buildings, Eastern Connecticut[16] Exposed friable ceilings, 5 to 30% chrysotile			
Custodial activities, heavy dusting	2.8	8	1.6
4. Private homes, Connecticut[16]			
Remaining pipe lagging (dry) amosite and chrysotile asbestos	4.1	8	1.8 to 5.8 (range)
5. Laundry: contaminated clothing.[20] Chrysotile	0.4	12	0.1 to 1.2 (range)
6. Office building, Connecticut.[16] Exposed sprayed ceiling, 18% chrysotile.			
Routine activity	79[a]	3	40 to 110 (range)
Under asbestos ceiling	99[a]	2	
Remote from asbestos ceiling	40[a]	1	
7. Urban Grammar School, New Haven.[16] Exposed ceiling, 15% chrysotile asbestos			
Custodial activity: sweeping, vacuuming	643[a]	2	186 to 1100 (range)
8. Apartment Building: New Jersey, heavy housekeeping.[16] Tremolite and chrysotile.	296[a]	1	
9. Office buildings, New York City.[16,18]			
Asbestos in ventilation systems Quiet conditions and routine activity	2.5 to 200[a]		0 to 800 (range)

[a] Nanograms/cubic meter. Determined by electron microscope.

significant, fiber levels may only be a few orders of magnitude above background levels in the hundreds of ng/m^3 range by electron microscopy,[18] and 0.2 f/cm^3 optically.[20] Routine activity may also, however, result in significant and intense contamination. A school population in a building with accessible sprayed asbestos surfaces may experience significant environmental contamination with exposures in the 10 to 50 f/cm^3 range.[20] Increased fallout, occasional contact, and reentrainment may all contribute to the highly variable fiber levels found under these activity conditions.

Custodial work will result in the disturbance and reentrainment of accumulations of asbestos fibers released from sprayed surfaces by fallout and contact. Exposure from reentrainment is high during custodial activity with variation depending upon both cleaning methods and proximity to the respiratory zone of the worker. Resulting levels may exceed OSHA occupational exposure limits.[20]

Maintenance work such as replacement of light bulbs may involve direct contact with sprayed asbestos surfaces and result in significant fiber dissemination. Such activities may also result in exposures that exceed regulatory limits established by OSHA. One study, for example, showed maintenance worker exposure above 20 f/cm^3 in a university building with exposed sprayed asbestos ceilings.[20]

Removal of sprayed asbestos surfaces during renovation not only causes high contamination levels for the duration of the work but also increases the released fiber burden within the structure that is available for subsequent reentrainment. In such cases, exposures involve the renovation worker and the routine building user as well. Both contact and reentrainment release mechanisms are involved with very high levels occurring during actual contact. Fiber concentrations can exceed 100 f/cm^3.[20,21]

Razing of a structure can result not only in high level local contamination, but can cause fiber contamination of the surrounding community due to the aerodynamic capability of the asbestos fiber. This type of activity is of great significance, but is beyond the scope of this report and is not considered further. The potential for continued exposure remains following a demolition operation if proper housekeeping or clean-up procedures are not followed. The operation cannot be considered complete unless the material removed is adequately sealed in bags and is disposed of in an approved sanitary landfill as required by EPA regulation.

2.4 ASBESTOS-RELATED DISEASES

Asbestos fibers find entry into the body by inhalation and ingestion. The retained mineral fibers are found in tissues throughout the lifetime of the host, even long after cessation of exposure.[22,23] Such asbestos fibers found in human tissues are generally undetected by optical microscopy, and require an electron microscope.[22-24] Fibers may migrate to other organs following retention in the lung.[25] Asbestosis and certain malignancies are related to exposure to fibers of the asbestos minerals. Asbestosis is a progressive restrictive pulmonary fibrosis associated with inhalation of asbestos fibers, and is a classic occupational disease.[26-34]

Malignancies related to the inhalation and possibly ingestion of asbestos fibers by epidemiologic studies include carcinomas of the lung, mesotheliomas of the pleura and peritoneum, and neoplasms of other sites.[35-37] Asbestos has a potent cocarcinogen effect with cigarette smoking in carcinoma of the lung. Asbestos workers who are smokers have over 90 times the risk of nonexposed nonsmokers.[38-40]

Both the presence of asbestosis and occupational asbestos exposures have been linked with the incidence of malignancy.[41-49] However, studies of the incidence of excess malignancies and the epidemiologic markers of pleural calcification and mesotheliomas have shown a much wider scope of asbestos-related malignancy.[50-53] The population at risk includes not only those engaged in the manufacture and use of asbestos products, but also bystanders and others limited to neighborhood and familial exposures.[54-59]

Definition of the relationship of low levels of asbestos exposure and carcinogenesis remains uncertain and difficult. The extended latency period, lack of adequate past exposure data, effect of other carcinogens, and variability of human response makes the quantification of risk approximate only. Asbestos-related malignancies exhibit latency periods of 20 to 40 years and may follow exposures of much less duration and magnitude as seen with asbestosis.[53-59,61]

Excess malignancies have been found in proximity to emission sources and in households of asbestos workers.[52,54,59] In these cases the exposures seem to have been variable and generally low (about 100 nanograms/ m^3).[18] Asbestos fiber contamination levels within or exceeding these ranges have been documented near building sites using sprayed asbestos,[7,18] within a university building with sprayed asbestos ceilings,[20] in offices, schools, and apartment buildings with exposed friable asbestos ceilings, with use of materials such as spackling compound,[62] and near roads and other areas covered with asbestos-containing crushed rock.[63] This indicates continuing environmental contamination and exposure to asbestos at levels considered carconogenic. An expanding population at risk has been identified by these findings of widespread exposure. The impressive annual asbestos production and evidence of urban environmental contamination has led observers to conclude that the incidence of asbestos-induced malignancies has only begun to be defined.[9,23,24,64-66]

3. EXISTING STANDARDS

Government regulations pertaining to sprayed asbestos materials have been issued at the federal level by the U.S. Environmental Protection Agency and the Occupational Safety and Health Administration, U.S. Department of Labor. Some state and local government units have also developed regulations pertaining to these materials. The OSHA Standard for Exposure to Asbestos Dust was published in the Federal Register,[67] Vol. 37, No. 110, on June 7, 1972 (29 CFR 1910.93a). This standard was recodified to §1910.1001 in the Federal Register dated May 28, 1975.[68] The regulations apply to handling asbestos fibers or material containing asbestos fibers, including removal procedures. This standard for occupational exposure defines permissible exposure limits, methods of compliance with regulations, personal protective equipment including clothing and respiratory protection, methods of measurement of airborne asbestos fibers, signs and labels warning of asbestos hazard, housekeeping methods for fiber control and waste disposal, recordkeeping for monitoring and exposures, and medical examinations.

The regulations originally stipulated a maximum exposure of 5.0 fibers/cm^3 greater than 5 μm in length over an 8-hour period on a time weighted average (TWA) basis. A maximum of 10.0 fibers/cm^3 for a 15-minute sampling period was the allowed any-time excursion. On October 9, 1975 OSHA proposed a limit of 0.5 f/cm^3 TWA and 5.0 f/cm^3 maximum excursion over a 15-minute period and on July 1, 1976 the original requirement in the regulation was reduced to 2.0 f/cm^3 with the maximum excursion permitted remaining at 10.0 f/cm^3.[69] Most recently, the National Institute of Occupational Safety and Health proposed to OSHA a further lowering of the TWA limit to 0.1 f/cm^3 TWA with 0.5 f/cm^3 as the maximum permissible any-time excursion.[70] These numerical limits are based partly on limited studies of asbestos carcinogenesis and it is possible that lower exposures may be significant.[71,72]

Regulations promulgated by the U.S. Environmental Protection Agency on April 6, 1973, apply to the renovation or demolition of structures containing asbestos and to the spraying of asbestos materials.[73] The national emission standard for asbestos[11] specifies procedures for removal and stripping of friable sprayed asbestos fireproofing and insulation materials and requires EPA notification that such removal is to take place. The required work practices include wetting, containment, container labeling and disposal of the removed material in an approved sanitary landfill. Fiber levels are not specified but the regulations require that there be no visible emissions exterior to the structure.

The spray application of asbestos material for fireproofing and insulation is prohibited where the material contains more than one weight percent asbestos. Decorative materials were not included in the ban, however, and this omission has permitted some continued application. One example includes all overhead surfaces in a large (1200 unit) condominium complex using a friable mixture of 30 percent asbestos.[12]

EPA has recently taken action to halt the spray application of asbestos containing materials for decorative and other purposes. On March 2, 1977, EPA proposed amendments to the national emission standard for asbestos.[74] These amendments would extend the spraying restrictions to all materials which contain more than 1 percent asbestos by weight.

Most state and local governments adhere to current EPA and OSHA regulations; however, in instances where the problem is acute or has received public attention, special bylaws or ordinances have been passed which are more stringent than federal regulations. For example, the State of New Mexico has a 10 ng/m^3 ambient air regulation,[75] and Connecticut has an ambient air limitation proposal of 30 ng/m^3.[76] The State Department of Environmental Protection for New Jersey issued a guidance document on this subject in May 1977 and California, Florida, Massachusetts, and Wisconsin have formed executive and legislative committees to assess the problem.

The New York City Council banned spray application in 1972.[10] Other cities and states have followed suit. The City of New Haven has a local ordinance prohibiting existing exposed friable ceilings of any asbestos content in dwelling.[77] This was enacted in 1977 and is presently being enforced in the case of an apartment building.

Since regulations affecting nearly all aspects of potential exposure to asbestos are changing rapidly, any questions concerning current EPA regulations should be referred to the regional office of the Environmental Protection Agency. Information on current OSHA regulations may be obtained from the U.S. Department of Labor — OSHA Regional Offices. A listing of the EPA and OSHA Regional Offices is given in Appendix I. State Departments of Health, Labor, and Environmental Protection will provide additional guidance in the event that more stringent state regulations are in effect, or if difficulty is experienced in locating an approved disposal site for the asbestos-containing debris.

4. ANALYTICAL TECHNIQUES

Two general areas of analysis are discussed within the scope of this document. The first, asbestos identification, is concerned with determining the presence, type and amount of asbestos within a bulk sample such as insulation or ceiling material. The second involves estimation of the amount of asbestos suspended in the ambient air. This airborne fiber concentration level can be used to estimate exposure risk. The techniques for examination of bulk samples are relatively straightforward and give an unambiguous result in most cases; however, the identification, and especially quantification of asbestos, in ambient air is very much "state-of-the art" — the methods used are somewhat controversial and the results ambiguous.

These two distinct types of fiber analysis may not be within the capability of the same commercial testing laboratory. It is emphasized that bulk sample analysis services to determine whether asbestos is present in the material are difficult to obtain. Moreover, the analysis must be performed in a competent manner otherwise it could lead to an expensive and needless removal task. Failure to identify asbestos fibers, on the other hand, would allow an existing hazard to continue.

Airborne asbestos fiber analysis is used for evaluating exposure and the effectiveness of fiber control during renovation, demolition, or removal. Here too, the number of commercial laboratories suitably equipped and staffed is limited.

4.1 BULK SAMPLES ASBESTOS ANALYSIS

There are three methods of asbestos fiber identification which are reliable and are in common use for bulk sample analysis: petrographic microscopy, X-ray diffraction, and electron microscopy.

4.1.1 Petrographic Microscopy

The petrographic microscope is a transmitted polarized light instrument, widely used in the geological and chemical sciences for identification and characterization of crystalline substances based upon their optical and crystallographic properties. The techniques are well established and the equipment is relatively low in cost. It is an effective method for identification of the particular mineral species present. A possible drawback in the use of petrographic microscopy is the high level of skill and experience required of the microscopist. Bulk sample optical microscopy involves the ability to adequately search a sample and successfully recognize and identify the suspect material. An experienced microscopist, however, should be able to locate and identify even small amounts of asbestos in bulk samples.[78,79]

4.1.2 X-Ray Diffraction

In this technique X-rays are diffracted by a small sample of the suspect material and a pattern uniquely characteristic of any crystalline materials present is produced. With some instruments a permanent diffraction tracing is produced. This method requires a significant investment in equipment, references, mineral standards, and technical expertise. In routine examination procedures, X-ray diffraction of bulk samples may fail to detect small concentrations of asbestos, and other silicates or cyrstalline phases may significantly interfere with accurate identification.

However, the technique usually yields information with a high degree of diagnostic reliability, and a printed record. It is usually used as a confirmation of petrographic microscopy impressions and not as a screening procedure.[80]

4.1.3 Electron Microscopy

Specific and accurate fiber identification can be achieved by examination of the structure of individual fibers or fibrils, especially if used in conjunction with electron diffraction or energy dispersive X-ray analysis. The extrapolation of precise electron microscope data, however, to significant bulk sample information is inefficient and costly. Its use in identification is usually confined to resolving ambiguities raised by petrographic microscopy and X-ray diffraction. The main use of the electron microscopy technique is in the examination of air samples.

4.2 AIRBORNE ASBESTOS ANALYSIS

Estimation of the amount of asbestos suspended in air is presently performed by two techniques:

1. Fiber counting by optical or light microscopy using the phase contrast technique.
2. Asbestos mass or fiber population estimation by electron microscopy.

For either method, a pump is used to draw a volume of air through a membrane filter at a known rate. An example of a unit specifically designed for this purpose is shown in Figure I-4-1. This sampling pump and filter are usually stationary, but other desigus may be carried by the worker with the sampling orifice near the respiratory zone. Common sampling rates are 2.0 liters per minute (ℓ/min) in low volume sampling, and 10 ℓ/min

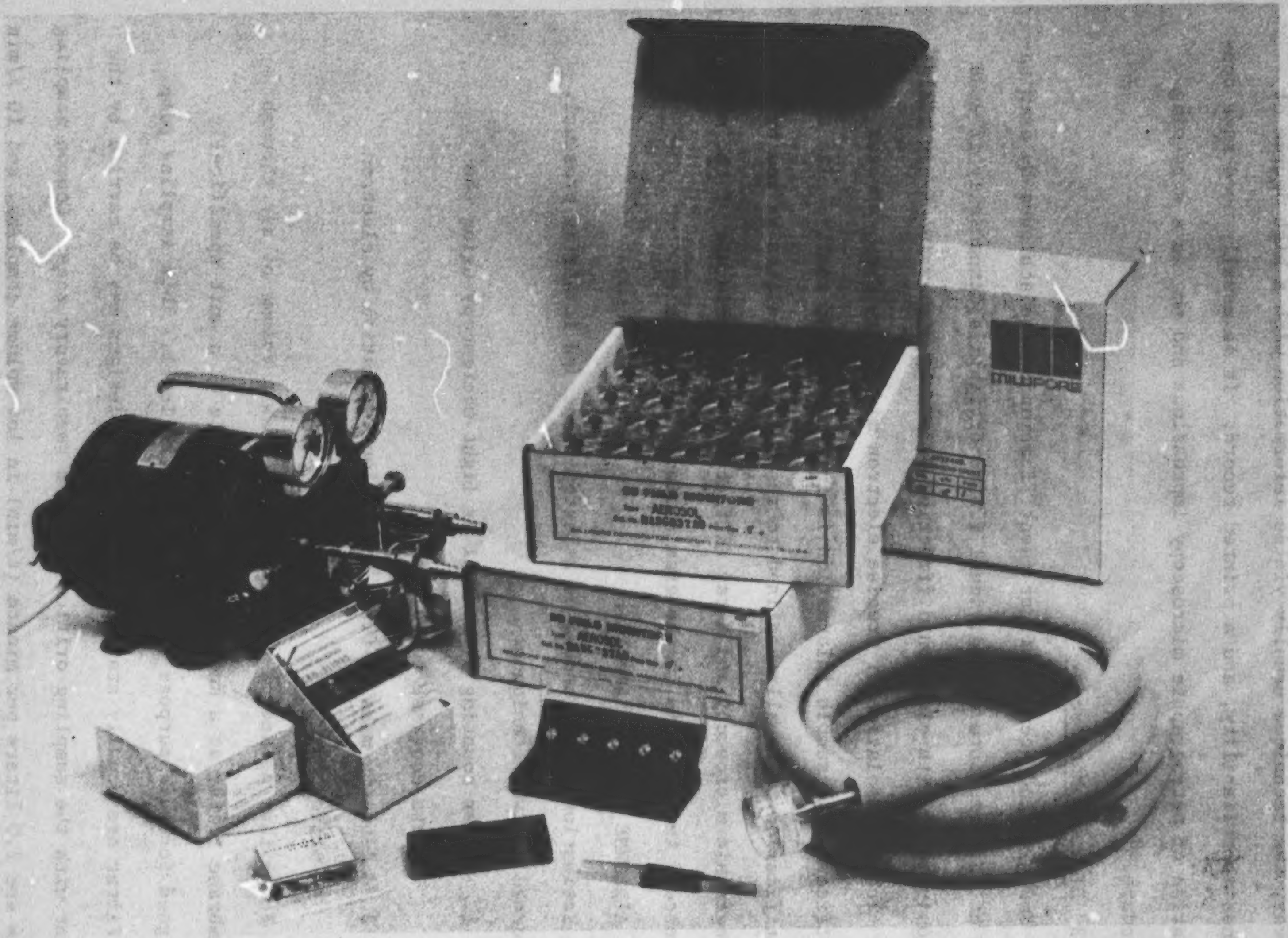
MILLIPORE
AEROSOL
AEROSOL

Figure I-4-1. Commercially available aerosol monitoring kit.
(Photo Courtesy Millipore Corporation, Bedford, Massachusetts)

in high volume sampling. The low volume rate is usual for personnel monitoring, and high volume for general environmental sampling. Sampling times are on the order of 30 minutes to 1 hour or more, depending upon anticipated fiber concentrations. The filter may be retained within its container and stored indefinitely. Also, each filter may be repeatedly counted since only a small segment is removed for each examination. The same filter may thus be examined by various methods of asbestos quantification and by several laboratories for comparison or verification. Care must be taken in transporting samples to avoid loss of fibers from the filter surface by mechanical agitation.

4.2.1 Fiber Counting by Phase Contrast Microscopy

Phase contrast microscopy is routinely performed following the optical method specified by Occupational Safety and Health Administration (OSHA) regulations for determination of airborne asbestos in occupational settings.[81] A pump draws air through a filter having an 0.8 μm effective pore size. A segment of the filter is then mounted, treated chemically to make the filter membrane transparent, and examined using a special microscope reticle and counting procedure with phase contrast illumination at 400 to 500 magnification.[81-83] Particles are observed for shape and size. Any particle having a length to width (or aspect) ratio greater than 3:1, and a length of 5 micrometers or greater, is counted as a fiber. Results are presented as the number of fibers per cubic centimeter of air (f/cm^3).

Phase contrast microscopy is an optical technique for viewing small particles rather than a method for measuring specific properties of a substance. It is a technique based entirely on the shape of the particle rather than a method for measuring specific properties of a substance. It is not inherently specific for asbestos. Consequently, all particles satisfying a 3:1 length to width ratio are counted as asbestos fiber. Also, both the resolution limit of optical microscopy (see Figure I-2-1) and the 5 μm lower cut-off for fiber length precludes identification of a much larger fiber population which may be present and which is of biologic significance. In some cases fibers and fibrils uncounted because of the 5 μm limitation of the standard may be greater in number than those counted by one or more orders of magnitude.[16,84] Some studies have indicated that fibers smaller than 5 μm possess potential for biological activity,[85] and that fibers of diameter less than 0.5 μm and length greater than 3.0 μm may be highly significant in carcinogenesis.[86,87]

4.2.2 Fiber Counting by Electron Microscopy

The electron microscopy (EM) permits detailed examination and identification of asbestos fibers of all sizes. Both scanning electron microscope (SEM) and transmission electron microscopy (TEM) are used. The magnification necessary to identify asbestos in its smallest dimension is within the range of these instruments. The actual counting is usually carried out at 15,000 to 20,000 magnification. Electron microscopy is presently the definitive method for fiber counting and exposure estimation. Following sample preparation, a large number of fields are examined for fibers. Each field is a few hundred micrometers square in area such that many fields must be examined to make the determination statistically valid. Each fiber observed is counted and its length (ℓ) and width (w) measured. The fiber volume can be calculated by assuming it to be either a right cylinder or tubular in shape. (The assumption of a cylinder gives a volume about

20 percent smaller.) The mass of fibers is estimated by multiplying the calculated volume by the mineral density, usually taken as 2.6 g/cm^3. The accuracy of the calculated fiber mass is primarily dependent upon the representativeness of the fiber population actually measured.

At this time, laboratories vary in sample preparation, instrument selection, and in results. There is presently no standard electron microscopy technique. A provisional optimum procedure is under development by the Environmental Protection Agency[*] and is intended to increase uniformity and enhance interlaboratory agreement.[88]

There has been great concern and some misunderstanding over inter- and intra-laboratory variability in fiber counting results. Apart from the errors to be anticipated from variation in laboratory procedures, high errors are intrinsic when extrapolating a count of possibly a few tens of fibers from a relatively miniscule fraction of a large sample to a total fiber count.[†] The multiplying factors used to scale-up the count for a specific volume of air may be as high as 10^6 or more.

The time required for sample preparation for EM techniques is lengthy, the equipment a major investment, and highly trained and qualified personnel a necessity.

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[*] This and other EPA documents are available through the National Technical Information Service (NTIS), 5285 Port Royal Rd., Springfield, Virginia 22161.

[†] It will be noted that determinations by optical (phase contrast) microscopy are expressed in numbers of fibers per unit volume of air whereas results by electron microscopy may be expressed either as number of fibers or mass of fibers per unit volume of air. The high resolution of the electron microscopy permits the analyst to measure the length and width of each fiber. Knowing the fiber's dimensions, its volume can be calculated (i.e., $\ell \times w^2$). Assuming a mineral density of 2.6 g/cm^3, the mineral's weight is obtained.

4.2.3 Conversion Between Optical and Electron Microscopy

The conversion of data obtained by one method to units of the other is not generally considered appropriate in the case of airborne asbestos measurement. The optical technique counts not only asbestos but all fibers generally, while EM is mineral specific. Fiber size range visible by EM is essentially complete, while that seen optically is truncated both physically and by regulation. In some cases the fiber size distribution will fall below 5 μm, producing a zero count optically, but will still have a significant count when examined by electron microscope.[16,20] Given the size distribution of a specific fiber population that extends above and below 5 μm such conversion is possible. However, in the general situation it is quite unreliable.

Table I-4-1 lists some advantages and disadvantages of analytical techniques available.

Table I-4-1. A COMPARISON OF ASBESTOS ANALYSIS TECHNIQUES AVAILABLE

Method	Advantages	Disadvantages
1. Bulk Sample Analysis		
a. Petrographic microscopy	Relatively rapid and low cost per analysis, suited for exact identification of mineral(s) present and estimate of abundance.	High level of operator training and experience required.
b. X-ray diffraction	Unambiguous mineral fiber identification, rapid "fingerprinting" of sample with permanent record.	High investment in training personnel and capital equipment. May not detect minor fiber abundances especially if other crystalline phases are present.
c. Electron microscopy	"Absolute" determination of fibers present, and identification of mineral species.	High equipment and analysis costs. Highly trained operator required.
2. Ambient Air Sample Analysis		
a. Phase contrast microscopy	Low cost per analysis, low cost for equipment, extensive training not required, presently the most detailed standard procedure available.	Limited resolution, fibers less than 5 μm not counted, therefore, hazardous situations may be missed altogether.
b. Electron microscopy	Closest to obtaining "absolute" fiber count because of high resolution and identification ability.	In addition to disadvantages in 1.(c) above, procedural standards not available, poor precision and accuracy.

PART II

THE CONTROL OF EXPOSURES TO SPRAYED ASBESTOS

1. DETERMINING ASBESTOS EXPOSURE LEVELS

1.1 INTRODUCTION

As discussed in Part I, exposure to asbestos fibers is a recognized health hazard. Following long latency periods, asbestosis and malignancies of varying type and site may follow both occupational and nonoccupational exposures. Although the mechanism and epidemiology of asbestos carcinogenesis is not yet well defined, accumulating evidence suggests the significance of exposures at even very low fiber concentrations.

The specific source of asbestos exposure covered in this document is fiber release from sprayed, friable asbestos-containing material. For approximately 20 years, sprayed asbestos was extensively used in the construction industry. The sprayed, friable material can release fibers into the environment at rates dependent upon both deterioration and the disturbance of the material. The released fibers are durable, possess aerodynamic capability, and are potentially carcinogenic without documented safe threshold levels.

The combination of the factors of widespread use, a large potentially-exposed population, and carcinogenicity has created a potential health hazard of significant proportion.

Part II presents recommendations for techniques of material analysis, procedures for hazard estimation, and alternative solutions to potentially hazardous situations. Regulations of the Environmental Protection Agency and the Occupational Safety and Health Administration are discussed in greater detail, and specific removal procedures and specifications are presented.

1.2 FACTORS TO CONSIDER

The applications, mixtures, and locations of sprayed asbestos material have been highly variable. The estimation of exposure hazard or risk from such material must involve consideration of a number of factors. There is no simple formula for all situations. The primary consideration should be to minimize exposure to asbestos. The following factors should be considered in assessing the risk of asbestos exposure and establishing priorities for corrective action:

1. Analysis of material. Establish the presence of asbestos in the sprayed material by competent examination. This is the first, and essential step in hazard estimation. The higher the proportion or percentage by weight of asbestos in the material, the greater the number of fibers released for a given event. However slight the damages, there will be a release of some fibers, and even friable material containing only 1 or 2 percent asbestos can disperse a significant number of fibers if it is extensively damaged.
2. Age and deterioration of the material. Cohesiveness of most materials will decline with age, and the rate of fiber loss will increase.
3. Location and accessibility of the material. With ceilings, for example, a height of approximately 10 ft (3 meters) is a reasonable limit for direct contact. Possibility of contact

for any other reason must be considered, however. This will include gymnasiums and classrooms where objects can be hurled against the fiber surface. The 3-meter rule would not apply in such circumstances.

4. Function of the space with respect to both the intended and actual use of the area. Population using space. This is a significant consideration. An active population, such as that of an urban senior high school may result in more contact fiber dispersal to a significant extent. High frequency of use and activity usually means high fiber levels in the space.
5. Necessity to penetrate or disturb the material for maintenance, cleaning, or any other reason. This includes penetrations for heating and ventilation, lighting, and plumbing.
6. Presence of high humidity or water damage. Although used for condensation control in some applications, sprayed asbestos-containing materials tend to deteriorate rapidly in humid environments and are susceptible to fragmentation from leaking water.
7. Accumulated epidemiologic evidence indicates that asbestos levels exceeding as little as 100 nanograms per cubic meter should be suspect in causing adverse health effects and thus some action to reduce exposure is warranted.[18] It may be advisable to determine levels elsewhere in the building and outside to ascertain that the fiber levels are due to the sprayed material rather than some other source.

8. OSHA, EPA, and state and local regulations will influence the selection of any action to reduce asbestos exposure levels. Until permanent action can be taken to reduce asbestos fiber release, temporary measures may be used. These include the alteration of various custodial and maintenance activities which can result in asbestos emissions by contact or by resuspension. Permanent actions include enclosure, encapsulation, or removal of the asbestos material.

1.3 ASBESTOS ANALYSIS

The methods of asbestos determination are listed in order of the simplest and least expensive (record review) to the more technical and costly (airborne fiber monitoring).

1. Record review: Architectural or contractor specifications and records are available for most large structures. In many instances these will identify the sprayed material and may include the type and proportion of asbestos contained. Instances where records erroneously report either the presence or absence of asbestos have occurred, and reliance on building records alone is not recommended.
2. Visual inspection: The surface of sprayed asbestos materials generally have an appearance that may vary from a loose, fluffy, or sponge-like composition to that of a dense, nearly solid surface. If the material is friable, it will crush with hand pressure. The thickness of most sprayed asbestos material commonly varies from 0.25 cm (1/8 inch) to over 5.0 cm (2 inches). Uncoated material may be slightly gray, brown, or blue in

coloration depending upon the proportion and type of asbestos used. Such surfaces readily collect dust, and will acquire a dark gray tinge with time. The presence or absence of asbestos, however, cannot be determined reliably by texture, color, or general appearance.

3. Bulk material analysis: The identification and quantification of asbestos in a bulk material sample is a procedure requiring appropriate equipment, technique, and expertise. In view of both the health and economic implications, competent analysis to determine the presence and proportion of asbestos is a necessity.

Laboratory analysis of the material should be performed by:

a. Petrographic microscopy as performed by a laboratory of recognized competence in optical crystallography.

b. X-ray diffraction as necessary as a supplement to petrographic microscopy.

c. Electron microscopy only if ambiguity exists following analysis by petrographic microscopy and X-ray diffraction.

It is again emphasized that the identification of asbestos in bulk samples involves expertise in optical crystallography and is not a routine laboratory procedure. A laboratory certified and proficient in NIOSH asbestos fiber counting methodology may lack both the equipment and competence for identification of asbestos in bulk samples. The use of polarized light microscopy (petrographic) and various refractive index liquids for dispersion staining is usually sufficient to allow identification of the individual forms of asbestos and estimation of the amount present.[79,87] An experienced microscopist using petrographic techniques is able to rapidly detect small quantities of asbestos in a bulk sample.

X-ray diffraction supplements optical microscopy by "fingerprinting" any crystalline phases present, though the presence of many of these phases in addition to asbestos may make interpretation difficult. X-ray diffraction provides a permanent tracing of the analysis, but is more expensive than petrographic microscopy, requires expertise, so does petrographic, and low quantities of asbestos fibers may not be detected. Depending on the laboratory, an amount less than 2 to 4 percent may be missed.

A recommended technique for obtaining a bulk sample from a sprayed asbestos material is outlined in Appendix C, along with cost and reference laboratory information.

4. Airborne asbestos fiber counting: Sampling and analysis for airborne asbestos may establish the existence of asbestos contamination.[12,20,21] An adequate study of airborne contamination requires sampling during various indoor activities and sampling of outside or community ambient levels, with inclusion of control samples. Sampling within a structure under only quiet conditions may be particularly misleading because asbestos fibers become airborne usually as a result of disturbance through human activity.[20] The direct monitoring of persons engaged in these activities will best define potential exposures.[16] These activities include usual behavior of building users, maintenance, custodial and housekeeping work.

If exposure levels are sufficiently elevated, examination of the samples by optical microscopy will probably determine the presence of asbestos. In cases of lower contamination levels or a predominantly small size population of fibers, electron microscopy will be necessary for complete asbestos quantification.

The lack of standards for airborne asbestos in nonoccupational environments and expense of sampling and analysis have discouraged airborne asbestos testing. An exposed and friable surface, the identification of asbestos within the material, and documentation of air contamination from such surfaces surely provide an impetus to reduce potential carcinogen exposure to as low a level as is possible.

2. ASBESTOS CONTROL MEASURES

2.1 TEMPORARY CONTROL MEASURES

During the interval between identification and resolution of an asbestos exposure problem it may be possible to significantly reduce exposure by control of maintenance, custodial, and repair activities. Temporary measures may include alteration of various work procedures such as maintenance or renovation that could potentially cause asbestos contamination. Wet cleaning methods for example, could be used in place of dry dusting and sweeping in any essential custodial work. In addition, maintenance and custodial workers should be protected by approved filtered respirators.

Building user and bystander exposure could be reduced substantially by appropriate rescheduling of necessary custodial and maintenance work. Table II-2-1 shows the reduction in fiber counts that was obtained in one case using wet cleaning methods and specific scheduling.[20] Custodial activities were categorized as above and below waist level. Air sampling was carried out at the respiratory zone of a worker wearing respiratory protection. While significant reductions were achieved, exposures were not eliminated and the use of such techniques should be temporary.

Table II-2-1. CUSTODIAL ASBESTOS EXPOSURES AND EFFECT OF WET METHODS

	Fiber count means: f/cm^3 (number)[a]	
Custodial activity	Before control	Following control
Above waist	4.0 (6)	0.3 (4)
Below waist	1.6 (5)	0.2 (4)
Bystander	0.3 (6)	b

[a] NIOSH method, phase contrast microscopy.

[b] Elimination of exposure to bystander by rescheduling should not be regarded as a permanent solution. The long settling times for fibers (see Figure I-2-2) and the possibility of resuspension should be considered before permitting normal traffic to resume in the area.

2.2 LONG-TERM CONTROL MEASURES

The long-term alternatives to reduce or eliminate asbestos exposure from sprayed friable asbestos material are outlined in Table II-2-2. Anticipated fiber concentrations, and comments on working conditions are included. These methods of resolution fall within two general categories:

1. Asbestos containment through use of a sealant (encapsulation) or barrier (enclosure) system.
2. Complete removal of the asbestos material from the structure.

Selection of the appropriate method or combination of methods will depend upon a number of factors including characteristics of the asbestos material, structure use and configuration, user activity, and cost.

Table II-2-2. ALTERNATIVES FOR REDUCTION/ELIMINATION OF CONTAMINATION FROM SPRAYED ASBESTOS

Alternatives	Typical fiber concentration in work area (f/cm^3)[a]	Comments
1. Removal		
a. Dry methods (loose material)	82.2[b] (11)[c]	Much dust and debris made work conditions difficult. Required hose supplied respirators (very restrictive). Fibers move across decontamination barriers.[20]
	>100.0 (-)	Very dusty conditions, contamination control impossible. Building contamination evident.[21]
b. Wet methods		
(1) Untreated (loose material)	23.1 (6)	Little dusting. Heavy water runoff.[20]
(2) Amended water (loose material)	2.8 (56)	Nearly no water runoff. Acceptable conditions. No visible dusting.[16,20]
(3) Amended water (loose material inadequate H_2O application	18.4 (12)	Some dusting evident. Dry patches in material noted.[16] Poor contractor performance in wetting material.
(4) Amended water (cementitious material)	0.5 (5)	No dusting noted, good penetration of water. Material falling off in sheets and chunks intact.[16]
2. Retention		
a. Ceiling barrier, lath (loose material). Dry	6.4 (9)	Contact and disturbance of material during installation by wood strips with visible emissions.[20]
b. Ceiling, hangers (loose material). Dry	1.1 (12)	Penetration of ceiling by hangers and subsequent disturbance by movement.[20]
c. Sealant, encapsulation (loose material).	0.0 (15)	Force of application varied during spraying adjustments. One air sample that produced a zero count by optical microscopy, had 7×10^3 ng/m^3 by TEM indicating significant small particle release by spray contact disturbance.[16]

[a] Determined by NIOSH Method, phase contrast microscopy.

[b] Mean.

[c] Number of observations.

Asbestos removal provides a final solution by elimination of the contaminant source. It requires, however, renovation involving friable asbestos material, with significant problems of worker protection, prevention of environmental contamination, and considerable interruption of activities in the building.

Containment by sealing, encapsulation, or barrier systems usually results in much lower levels of asbestos contamination during alteration, takes less time, and may be less expensive, especially if replacement is avoided. The asbestos source remains, however, and damage, deterioration, or failure of the protective system will result in recurrence of asbestos contamination. Consequently, if asbestos containment is selected as the long-term solution, then some form of continuous or semicontinuous ambient monitoring program is necessary to assure that the protective system maintains its integrity over time. Maintaining low fiber levels may require strictly controlled maintenance and custodial activities for the life of the building. Also, the problem of asbestos exposure and environmental contamination will present itself again at the time the building is demolished.

2.3 ASBESTOS EMISSION CONTROL AND PERSONNEL PROTECTION

The work associated with asbestos containment or removal involves disturbance of the fiber matrix by contact, with dispersal of fibers into the environment. The dispersal is massive in dry removal of loose friable material; localized, but high, in installation of hangers or lath for a barrier system and can be significant even in spraying a sealant onto a friable asbestos surface. Whatever course of action is selected for asbestos containment or removal, asbestos contamination or emission control and personnel protection are required by EPA and OSHA regulations to prevent exposure of workers, bystanders, building users, and the community. Asbestos contamination control minimizes fiber dispersal in the removal area, fiber emissions to the outside environment, and residual asbestos contamination. The basic steps are:

1. Fiber containment: Barriers will prevent movement of fibers to other building spaces and into the community. Barrier systems should be used to enclose any work area and may be used to isolate a room or an entire building. Ventilation and heating systems must be shut down and all openings and vents sealed, and any building equipment or furniture enclosed in a protective cocoon. Any object, duct, window, or passageway that could be contaminated should be isolated. Special care should be taken to locate and seal all possible openings.
2. Fiber control: Wetting the asbestos-containing material will reduce friability and change the aerodynamics of the released fibers. The addition of a wetting agent will enhance penetration, reduce the amount of water needed, and generally increase the control effectiveness.

Since fiber dispersal probability and concentrations are potentially high, protection of working personnel is necessary and includes instruction, respiratory protection supervision, and decontamination. The following list is considered appropriate to both provide and document worker protection. This protection should also apply to any other person entering a removal job site.

1. Instruction: OSHA regulations specify the use of certain equipment, decontamination procedures, and work sequences. Adequate instruction of the work force is absolutely essential.
2. Respiratory protection: Each worker should be afforded respiratory protection as appropriate to anticipated fiber levels according to OSHA regulations 29 CFR 1910.1001.
3. Supervision: Adequate supervision is necessary to maintain the performance required for safety. Adequate instruction will help to a great extent, but continuously effective respirator use and decontamination will depend upon continuous and effective supervision.
4. Personnel decontamination: Following each day's activities, decontamination is necessary to prevent exposure of family and personnel contacts. A decontamination facility should be provided and include a changing room, shower room, and equipment storage area. An outline of a decontamination procedure is given in Appendix D.

3. ASBESTOS CONTAINMENT

3.1 ENCLOSURE SYSTEMS

Enclosure of a sprayed asbestos surface places a barrier between the asbestos-containing material and the area of activity. Either a suspended barrier or an attached lath system is usually used. Depending upon the integrity and type of barrier system, a dissemination of fibers by fallout will take place behind the barrier only, and exposures below the barrier will be greatly reduced. Contamination from contact will theoretically be prevented by the barrier. A barrier system must not connect with an air plenum system, and the enclosed space should not communicate in any way with portions of the occupied building.

Installation of hangers or lath necessitates contact and penetration and will result in asbestos fiber dissemination, frequently in excess of existing OSHA regulations. Consequently, worker exposure protection in accordance with OSHA should be required during this work. Furthermore, fiber dissemination by fallout will continue with accumulation of fibers behind the barrier system. Consequently, entry into these areas will require protection and fiber containment precautions.

The uncertainties in its long-term effectiveness, the need for continued air monitoring, and the remaining problem at the time of demolition or renovation make this method unattractive.

3.2 ENCAPSULATION WITH SEALANTS

Encapsulation with sealants may make replacement of sprayed asbestos materials unnecessary. The use of a sealant means retention of the asbestos material and recurrence of the problem if the sealant is damaged or penetrated. In addition, this postpones asbestos control to the time of major renovation or building demolition. The use of sealants may be restricted by characteristics of the sprayed asbestos surface itself. The integrity of an encapsulated surface depends upon bonding between the sprayed asbestos material and supporting structural members. A sprayed asbestos ceiling for example, with initially poor adhesion to a smooth hard structural ceiling surface will result in shearing and failure of the full thickness of sprayed material and the applied sealant. Accessibility and user behavior should also be carefully considered. Sealant used on asbestos surfaces within reach of children in a school will probably be damaged eventually leading to continued asbestos exposure.

The sealing of sprayed asbestos surfaces involves applying material that will envelop or coat the fiber matrix and eliminate fallout and protect against contact damage. Sealants are usually applied to asbestos surfaces by spraying and consist of polymers with an agent added to enhance penetration into the fiber matrix. Sealants which are currently available include water-based latex polymers, water soluble epoxy resins and organic solvent-based polymers of various types.

Nearly any sealant or encapsulation method will reduce fallout contamination. The more effective sealants, however, will have resistance to impact and will reduce asbestos release due to contact. In one study, latex paint sprayed over a friable asbestos surface was effective in reducing background fiber levels in the building from fallout. This coating failed, however, to significantly reduce building asbestos exposure levels during routine activity due to contact or reentrainment.[20] Even in the case of a fairly resistant sealant, suitable protection should be used against heavy physical damage. A system of routine inspection and repair should insure the integrity of a sealant system.

Application of a sealant by spraying will cause dissemination of small fibers by contact. A sealant should be applied with as much caution and at as low a nozzle pressure as possible to reduce contact disturbance. The potentially high concentration of small asbestos fibers could cause significant worker exposure and thus, workers require protection with respiratory devices and decontamination. Such asbestos fiber contamination from application of sealants is usually not detectable by the NIOSH method of optical microscopy, and may require electron microscopic examination for definition.[12,62]

An effective sealant should possess the following characteristics:

1. The sealant should eliminate fiber dispersal by adhering to the fibrous substrate with sufficient penetration to prevent separation of the sealant from the sprayed asbestos material.
2. It should withstand most impact and penetration and still protect the enclosed sprayed asbestos material.
3. It should possess enough flexibility to accommodate atmospheric changes and settling of the structure over time.
4. It should have high flame retardant characteristics and a low toxic fume and smoke emission rating. This is, of course,

essential if the enclosed sprayed asbestos material was used initially for fire retardation and protection of structural members.

5. It must be easily applied by nonspecialized personnel, with relative insensitivity to errors in preparation or application. Ease of repair by routine maintenance personnel is desirable.
6. The sealant must be neither noxious nor toxic to application workers and structure users thereafter. Since spraying creates fiber dissemination and exposure, fiber containment by barriers is desirable during application even though this may be incompatible with ventilation necessary for toxic vapor removal.
7. It should have some permeability to water vapor to prevent condensation accumulation, and resistance to solution by common cleaning agents.
8. It should have suitable stability to weathering and aging.
9. It should be acceptable by architectural and esthetic standards.

Sealant selection and application should be made with consideration given to the configuration, dimensions, use and characteristics of the structure involved. The listed characteristics above may assume differing levels of importance in consideration of the specific application. Additional considerations in selecting a sealant are:

1. The coated structural member should be inspected. Bonding between the sprayed asbestos material and structural member must be adequate to accommodate the added weight and cohesive mass of the encapsulated asbestos material.

2. Sealants are not generally recommended when surfaces are accessible to physical damage, such as low ceilings in school corridors or stairwells.
3. The cost of asbestos stripping versus encapsulation should be estimated. A complex or relatively inaccessible surface may defy economical asbestos removal, and present an ideal situation for encapsulation.
4. Replacement material needs for fireproofing and thermal or acoustical insulation must be met after removal. Such replacement may be avoided by encapsulation.
5. The moving of furniture, equipment, or partitions necessary in asbestos removal may be significantly reduced if encapsulation is used.

Sealants for asbestos material are presently being evaluated by the Environmental Protection Agency, Power Technology and Conservation Branch, Industrial Environmental Research Laboratory, Cincinnati, Ohio 45268.

4. ASBESTOS REMOVAL

Building characteristics, the inability to eliminate exposure, and the uncertainties of asbestos disease epidemiology may be the crucial factors in the decision to remove the sprayed friable asbestos materials. Both EPA and OSHA regulations influence the manner in which asbestos stripping or removal is accomplished. Work practices during asbestos stripping and disposal operations are covered by EPA regulation 40 CFR 61, subpart B: National Emission Standard for Asbestos.[90] Landfill disposal and site requirements are covered by 40 CFR 61.25, waste disposal sites. Worker protection during removal or stripping operations is covered by OSHA regulations 29 CFR 1910.1001, occupational exposure to asbestos. These regulations are discussed in detail in Appendices G and H.

4.1 DRY REMOVAL

Dry removal of untreated friable asbestos material is definitely not recommended, but may be necessary in instances of unavoidable damage through the use of wet removal techniques. Dry removal requires specific EPA approval. As shown in Table II-2-2, dry removal results in heavy airborne asbestos contamination with fiber counts that can exceed 100 f/cm^3. The potential for worker, structure, and community contamination is high, and complete fiber containment by a series of barriers is necessary, along with an elaborate system for debris removal and worker decontamination. Studies have shown that significant contamination can occur across a double barrier entrance under working conditions during dry removal. Considering existing data on dry removal and fiber behavior in settling and movement, contamination spread and heavy exposure appear unavoidable.

Dry vacuum methods for rapid removal of debris from demolition areas rely upon evacuation of all fallen visible asbestos material through vacuum lines that penetrate the barrier system. The material is drawn through the lines to a point usually outside the structure, deposited in sealed containers, and the accumulated material removed to a disposal site. The vacuum system exhaust is filtered to prevent contamination of the external environment. A vacuum system using an extraction air velocity 1 meter/second (200 ft/min) and an HEPA (high efficiency particulate) filtered exhaust is in use in Great Britain.[91] Evaluation of both internal containment and external exhaust cannot be considered complete because of a lack of appropriate air sampling data.

4.2 WET REMOVAL

Wet removal is based upon the ability of water to lower both the friability of the sprayed material and the aerodynamic capabilities of the released fibers. Water will render the material less friable and more cohesive, and greatly reduce the release of fibers, thus reducing airborne asbestos levels. Fibers that are released will fall rapidly if wet. A suggested work sequence for wet removal is listed in Appendix E.

Table II-2-2 lists anticipated fiber contamination levels using water. As shown, asbestos exposure levels may be reduced by as much as 75 percent using wet removal rather than dry removal. The use of plain water, however, is not entirely satisfactory because of slow penetration, incomplete wetting, and bothersome runoff. Even with extensive soaking, areas of dry material will remain. The runoff not only is a safety and cleanup problem, but the resulting slurry will carry fibers to other areas where they will reentrain following evaporation.

Water penetration into a hydrophobic fiber matrix is significantly increased with a wetting agent or surfactant. "Wet" water is a common item in use by fire departments, industry, and agriculture.[92] This technique greatly reduces the amount of water needed for saturation, increases the cohesiveness of the fiber matrix, and increases the probability of individual fiber wetting. This effect, as shown in Table II-2-2, results in a significant improvement in working conditions and significantly reduced environmental contamination. Use of amended water can reduce fiber counts by more than 90 percent as compared to dry removal. This reduction of fiber contamination within the work area not only reduces potential worker exposure but relieves much of the dependence upon containment barrier systems for isolation of fibers within removal areas. Table II-4-1 lists some wetting agents available commercially.

Table II-4-1. COMMERCIALLY AVAILABLE WETTING AGENTS FOR WET REMOVAL OF ASBESTOS IN BUILDINGS[a]

Aquatrols Corp. of America 1400 Suckle Highway Pennsauken, NJ 08110	Leffingwell Chemical Co. Box 188 Brea, Calif. 92921
Occidental Chemical Co. Institutional Division Box 198 Lathrop, Calif. 95330	Rohm and Haas Co. Ag. Chemical Dept. Independence Mall W. Philadelphia, Pa. 19105
Target Chemical Co. 1280 N. 10th St. San Jose, Calif. 95112	Thompson-Hayward Chemical Co. Box 2383 Kansas City, Kans. 66110
Vineland Chemical Co. Box 745 Vineland, NJ 08360	

[a] The inclusion of this information should not be construed as a product endorsement by the EPA or the authors.

5. REGULATIONS AND COMPLIANCE BY CONTRACTORS

Fiber control, containment and worker protection are necessary in asbestos abatement work since there will be environmental contamination regardless of the work method used. A considerable potential will exist not only for worker exposure, but also contamination of the structure, the community, and worker homes.

In most operations there has been an effort by the contractor to minimize asbestos contamination by compliance with OSHA and EPA regulations and by additional control procedures as appropriate.[16,20] However, in some operations violations of both regulations and common sense have occurred. Some contractors have removed asbestos absolutely dry instead of wet as agreed, removed asbestos without respirators, dropped asbestos-loaded bags down laundry chutes where they have ruptured, served coffee in removal areas, and allowed heavily contaminated workers to leave the job site.[16,21]

A number of factors will influence contractor work practices:

1. Attitude of purchaser of services: The purchaser of service will be motivated to control asbestos exposure for various reasons. These may include concern for well-being of building users, fear of future legal involvement and claims by users or their survivors, or fear of employee or union

action. Asbestos exposure situations have, on occasion, become political issues, a cause of panic and overraction, and a sensationalistic subject for the press. The climate created by these pressures has caused careless and misinformed actions that can lead to increased exposures rather than decreased exposures. The harassed school principal, apartment building owner, or corporation executive often seeking the quickest and cheapest contractor services may create a potential for significant exposures and contamination.

Once a contractor leaves the job site, there are currently no regulations protecting building users. Poor clean-up of the removal area can lead to continual reentrainment and resuspension. To ensure proper clean-up by the contractor, the purchaser of contract services should provide the contractor with definitive job specifications for asbestos removal. An example is included in Appendix F.

2. OSHA regulations: In general, the OSHA regulations are effective in routine occupational asbestos exposure situations at a fixed location. However, application to transient demolition workers who have no fixed place of employment is difficult. Demolition and removal operations are mobile, often brief, quite variable in conditions. Exposures, however, may be extremely high. Present regulations do not require worker instruction regarding the hazards of asbestos exposure and the use of respirators.

Also, there are ambiguous requirements for decontamination since the place of employment is not fixed. Showering is not presently required. (Proposed OSHA regulations address these points with specific regulations requiring instruction, respiratory protection, reporting, and decontamination by showering for any regulated area where exposure occurs.)

3. EPA regulations: The EPA regulations cover emissions into the outside environment, and disposal of material from job sites. Regulatory coverage does not apply to the building environment apart from the prohibition of many initial uses of asbestos materials.

4. Contractor economics: Protection of workers, building users, and the general community, means time, effort, and cost to a contractor. The contractor who is both aware and concerned about these problems faces economic pressure from those who are not. This is not only discouraging, but in a low bid competition may mean the difference in the awarding of the contract. Consequently, safety precautions may be compromised. As yet, there is no generally applicable equalizing force such as enforced regulations or licensing of qualified contractors. Consequently, as recommended above, the purchaser must write definitive job specifications to ensure the use of adequate safety measures by contractors.

5. Contractor and worker attitudes: Asbestos is a material that has been used in construction for some time, and its carcinogenic potential has only recently gained recognition.

Many workers have become accustomed to handling asbestos without precaution, and retraining is difficult. Compounding this is the fact that the latency period of asbestos-related disease is frequently quite long. This has not only blurred the vision of professional observers, but has blinded that of many workers and contractors to the consequences of asbestos exposure. Unconcerned or uninformed removal workers incur exposures for themselves, fellow workers, and their families.

Contract specifications written for asbestos work should effectively complement OSHA, EPA, and local regulations and may include specific requirements for exposure and contamination prevention. The informed purchaser, or one who must satisfy an informed building user and community, will be motivated to define contractor performance in asbestos work. Such specifications may include requirements for contractor competence in asbestos removal, OSHA and EPA compliance, special contamination control, and air sampling. Such specifications essentially restrict bidding contractors to those who know the work and regulations. This will encourage and protect the competent contractor's investment in equipment and training. Definitive job specifications for asbestos removal similar to those presented in Appendix F, therefore, are recommended.

APPENDICES

APPENDIX A

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APPENDIX B

AERODYNAMIC BEHAVIOR OF AIRBORNE FIBERS

The aerodynamic behavior of fibrous-shaped aerosol particles is governed by the interaction of opposing forces: a driving force such as is caused by gravitational acceleration, and the viscous resistance of the gaseous medium within which the particles move. In this context, a useful characterizing parameter is the aerodynamic equivalent diameter, defined as that diameter of a sphere of unit density whose settling velocity equals that of the particle under consideration. Although this equivalence applies to particles of any size. this approach is usually limited to motion in the Stokes regime; i.e., where viscous drag predominates. The theoretical modeling of fiber aerodynamics becomes rather complex when slip corrections are required;[93] i.e., when the aerodynamic dimensions of the particle approach the molecular mean free path of the gas matrix. At the other extreme, when the fiber Reynolds number (referred to its diameter) exceeds the range from about 0.1 to 1, drag coefficient corrections become significant.[94]

In practice, most particles of biological interest, including those of fibrous shape, fall well within the range covered by the Stokes model. The generally accepted theoretical model for the calculation of the equivalent aerodynamic diameter of the fibers is based on the assumption that the fibers can be approximated by ellipsoids of revolution. This concept has also been used to predict the deposition of fibers in the human respiratory system.[95,96]

Two extreme cases can be recognized: (1) motion of the ellipsoid (or fiber) along its axis of revolution, and (2) motion perpendicular to the axis of revolution. It should be considered that the gravitational settling motion of any particle with three mutually perpendicular planes of symmetry (such as an ellipsoid of revolution) will be invariant during its descent, maintaining its initial orientation through its fall trajectory. In practice, however, asbestos fibers, for example, may not always be perfectly straight and the above-mentioned rule may not hold.

As noted above, acicular particles can be approximated by ellipsoids of revolution falling under the action of gravity in either of two attitudes described under (1) and (2), or any intermediate angle with respect to the direction of motion. In general, an acicular particle falling with its axis vertical will have a higher terminal velocity than the case when its axis is normal to the direction of motion. Intermediate angles will exhibit intermediate velocities.

Two equations represent the two extreme axis-to-motion angles defined above:[97]

For case (1): $$D_1 = \frac{4/3\ d}{\frac{2\beta^2-1}{(\beta^2-1)^{3/2}} \text{ arc cosh } (\beta) - \frac{\beta}{\beta^2-1}} \tag{1}$$

and for case (2): $$D_2 = \frac{8/3\ L}{\frac{2-3\beta^{-2}}{(1-\beta^{-2})^{3/2}} \text{ arc cosh } (\beta) + \frac{1}{1-\beta^{-2}}} \tag{2}$$

where D is the diameter of the sphere having the same settling velocity.

L is the ellipsoid major axis length (or fiber length)

d is the ellipsoid minor axis length (or fiber diameter)

β is the length-to-diamter ratio, L/d or aspect ratio.

Equations (1) and (2) have also been expressed as:[98]

$$D_1 = \frac{8}{3} d \left[\frac{-2\beta}{\beta^2-1} + \frac{2\beta^2-1}{(\beta^2-1)^{3/2}} \ln\left(\frac{\beta + \sqrt{\beta^2-1}}{\beta - \sqrt{\beta^2-1}} \right) \right]^{-1} \tag{3}$$

and

$$D_2 = \frac{8}{3} d \left[\frac{\beta}{\beta^2-1} + \frac{2\beta^2-3}{(\beta^2-1)^{3/2}} \ln(\beta + \sqrt{\beta^2-1}) \right]^{-1} \tag{4}$$

which for the case β > > 1 can be approximated by:

$$D_1 = \frac{2\ d\ \beta}{3(\ln(2\beta) - \frac{1}{2})} \tag{5}$$

and

$$D_2 = \frac{4\ d\ \beta}{3(\ln(2\beta) + \frac{1}{2})} \tag{6}$$

respectively

Once the value of D has been determined for a given particle, and provided that the particles fall vertically (no lateral glide) and do not change their orientation during their vertical motion, D can be replaced in the classical Stokes equation for a spherical particle, in order to calculate its settling velocity:

$$V_s = \frac{(M_p - M_g)g}{3\pi\ \eta D} \tag{7}$$

where V_s is the settling velocity

M_p and M_g are the masses of the particle and the displaced gas, respectively

(M_g is usually negligible)

g is the acceleration of gravity
η is the coefficient of gas viscosity.

The rigorous equations presented above were solved for the typical density of asbestos fibers of 2.6 g/cm^3 and for air at standard conditions. The results are shown in Figure B-1, which is a plot of fiber settling velocity as a function of fiber length and diameter for the two axis-to-motion orientations mentioned above. These curves show that the settling velocity of fibers is only weakly dependent on fiber length but strongly dependent on fiber diameter, and that in the limit ($\beta \rightarrow \infty$) the settling velocity for a vertical fiber is twice that of a horizontally falling fiber.

In practice, for straight fibers the settling velocity will probably fall between the two extreme orientation values, because the fiber axis will be changed randomly as a result of Brownian molecular bombardment and in the case of nonstagnant air conditions, by large-scale turbulence. It is of interest to note that for fibers whose diameter is of the order of 0.1 μm, gravitational sedimentation occurs at the rate of only a few centimeters per hour, even though their length may be as much as 100 μm.

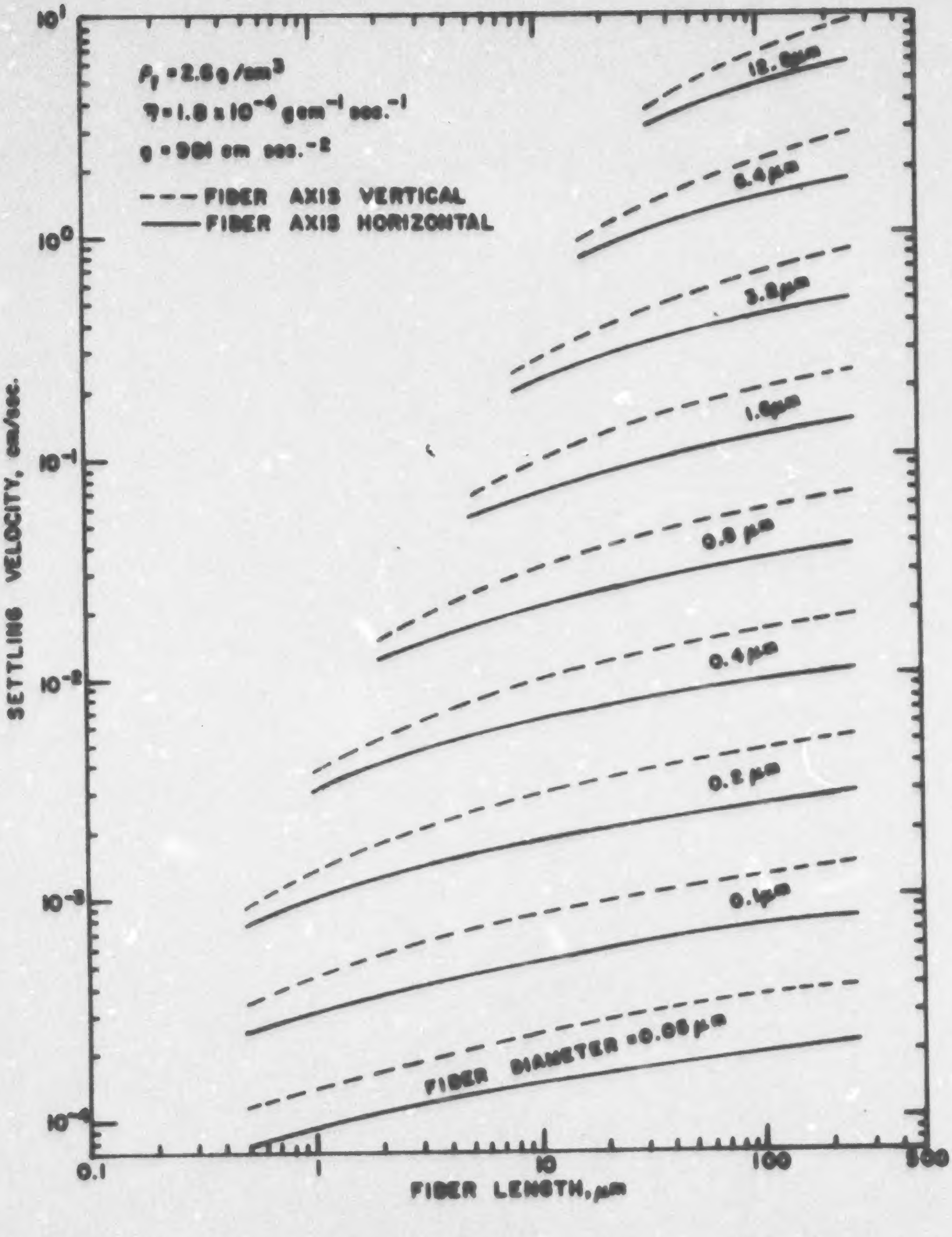


Figure B-1. Fiber settling velocities as a function of fiber length.

APPENDIX C

ASBESTOS SAMPLE COLLECTION

C.1 BULK ASBESTOS SAMPLE COLLECTION

A bulk sample is collected to determine whether the ceiling or other construction material contains any asbestos mineral. Use a small sealable glass or plastic-capped container. Holding the container as far as possible from the face, obtain a full thickness core sample of the sprayed material by penetrating the surface with the container using a twisting motion. Any surface coating such as paint on a cement material must be penetrated. The container is then capped, wiped, and sealed with tape. Labeling should include building identification, address, building type, sample source location, and date. Disturbance of the material other than at the sampling point should be kept to a minimum. A respirator approved for asbestos dust will insure protection while performing this work.

Repeat the procedure at several adjacent sites.

Approximate sample analysis costs for bulk material sample:

Method	Approximate cost
Petrographic microscopy with dispersion staining	\$25.00 - \$100.00[a]
X-ray diffraction	\$75.00 - \$150.00

[a] Cost per sample generally varies with total number of samples submitted.

C.2 AIR SAMPLING FOR ASBESTOS FIBER

This procedure is followed to estimate concentration levels of airborne fiber before, during and after a removal or encapsulation operation. The source method also serves long-term ambient-air monitoring requirements following a sealing operation or installation of a barrier system. The general procedure calls for drawing a known volume of air through a membrane filter using a calibrated sampling pump. Procedural details suggesting sampling times and other parameters, and sources of equipment are available in the literature.[82,83,88,89] Analysis of the membrane filters can be carried out by either phase contrast Optical Microscopy or by Scanning or Transmission Electron Microscopy. While the former technique is less costly, the latter gives a more complete estimate of number and size of fibers present. The latter technique (EM) is especially valuable in distinguishing mineral fiber from cellulose, glass fiber or other fibers which may be present in the material being removed.

Price range for asbestos fiber analysis in air samples.

Method	Approximate cost
Phase contrast optical microscopy (NIOSH Method)	\$35.00 - \$50.00
Electron Microscopy (SEM, TEM)	\$300.00 - \$500.00

A list of laboratories accredited for phase contrast microscopy asbestos counting (NIOSH) may be obtained from the American Industrial Hygiene Association, 66 South Miller Road, Akron, Ohio 44313.

APPENDIX D

RECOMMENDED DECONTAMINATION PROCEDURE

An adequate decontamination area consists of a serial arrangement of connected rooms or spaces. All persons without exception should pass through this decontamination area for entry into and exit from the work area for any purpose. Parallel routes for entry or exit are not recommended; if such routes exist they will eventually be used.

D.1 DECONTAMINATION AREAS

1. Outside room (clean area): In this room the worker leaves all street clothes and dresses in clean working clothes (usually disposable coveralls). Respiratory protection equipment is also picked up in this area. No asbestos contaminated items should enter this room. Workers enter this room either from outside the structure dressed in street clothes, or naked from the showers.

2. Shower room: This is a separate room used for transit by cleanly dressed workers entering the job from the outside room, or by workers headed for the showers after undressing in the equipment room.

3. Equipment room (contaminated area): Work equipment, footwear, additional contaminated work clothing are left here. This is a change and transit area for workers.

4. Work area: The work area should be separated by polyethylene barriers from the equipment room. If the airborne asbestos level in the work area is expected to be high, as in dry removal, an additional intermediate cleaning space may be added between the equipment room and the work area.

D.2 DECONTAMINATION SEQUENCE

1. Worker enters outside room and removes clothing, puts on clean coveralls and respirator, and passes through into the equipment room.
2. Any additional clothing and equipment left in dirty room required by the worker is put on. (When the work area is too cold for coveralls only, the worker will usually provide himself with additional warm garments. These must be treated as contaminated clothing and left in the decontamination unit.)
3. Worker proceeds to work area.
4. Before leaving the work area, the worker should remove all gross contamination and debris from the overalls. In practice this is usually carried out by one worker assisting another.

5. The worker proceeds to equipment room and removes all clothing except respiratory protection equipment. Extra work clothing may be stored in contaminated end of the unit. Disposable coveralls are placed in a bag for disposal with other material. The worker then proceeds rapidly into the shower room. Respiratory protection equipment should be removed last to prevent inhalation of fibers during removal of contaminated clothing.
6. After showering, the worker moves to the clean room and dresses in either new coveralls for another entry or street clothes if leaving.
7. Respirators are picked up, cleaned and wrapped by protected workers in a separate area by washing. The respirators are then brought to the clean room by an outside worker. The cleaners then exit through the shower units as usual.

APPENDIX E

STRIPPING SEQUENCE FOR WET AND AMENDED WATER METHODS

PREPARATION

1. Isolation of the work area heating and ventilation system is carried out first to prevent contamination and fiber dispersal to other areas of the structure during stripping.
2. The work area is prepared by removing as much furniture, equipment, and miscellaneous items as possible. Anything remaining should be sealed with polyethylene sheeting. It should be noted that in situations of deteriorating asbestos surfaces such activity may result in contact and reentrainment contamination to significant levels, and personnel protection should be used.
3. The removal area is isolated, restricting access according to OSHA regulations. This is done by sealing corridors and entry ways with polyethylene barriers. The decontamination area should be set up at this time.
4. Removal of ceiling mounted objects such as lights, partitions, and other fixtures should precede the actual asbestos removal operation. This will usually result in contact with the ceiling with potential significant exposure. Localized water spraying during fixture removal will reduce fiber dispersal.

5. Asbestos removal: Water spraying with respraying as required if dust occurs during removal of the material by dislodgement and scraping. (See Figure E-1).

6. Removal of debris: Collection of the material and labelling according to OSHA regulations using six mil or heavier plastic bags. The use of 55-gallon drums is strongly recommended as a secondary containment system for the bags. (See Figure E-2).

7. Gross clean up: All debris must be placed in bags and drummed for disposal. Spraying of fallen material may be required since higher counts are possible during this operation. Continued spraying of the fallen material is recommended. It should be noted that water-soaked fall material left overnight can lose much of its water content due to evaporation.

8. Repeated cycles of cleaning at intervals is suggested to collect settled fibers. A minimum of two such cycles is recommended with 24 hours intervals between.

9. Disposal: Disposal should be in accordance with EPA guidelines. Special high cost hazardous waste material disposal services are usually not necessary if the sanitary landfill disposal area and procedures are performed within the EPA regulations.

10. Stringent visual inspection of the removal site should be performed to insure adequacy and completeness of the removal procedure.

11. Air sampling: Airborne asbestos sampling should be performed both during and following asbestos stripping operations. During stripping sampling in the removal work area, outside

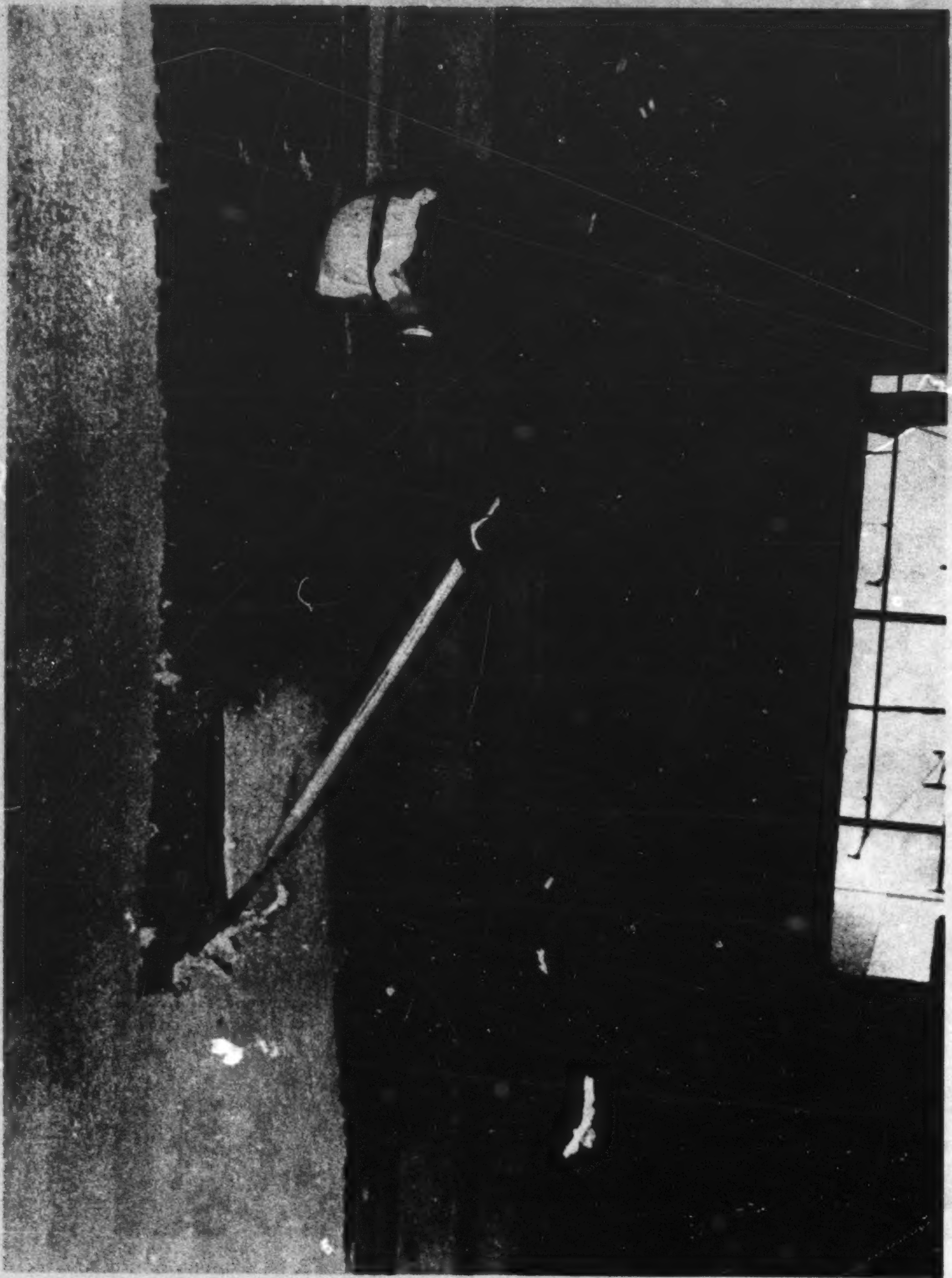


Figure E-1. Removal of asbestos-containing ceiling material. Note use of headgear, coveralls and respiratory protection.

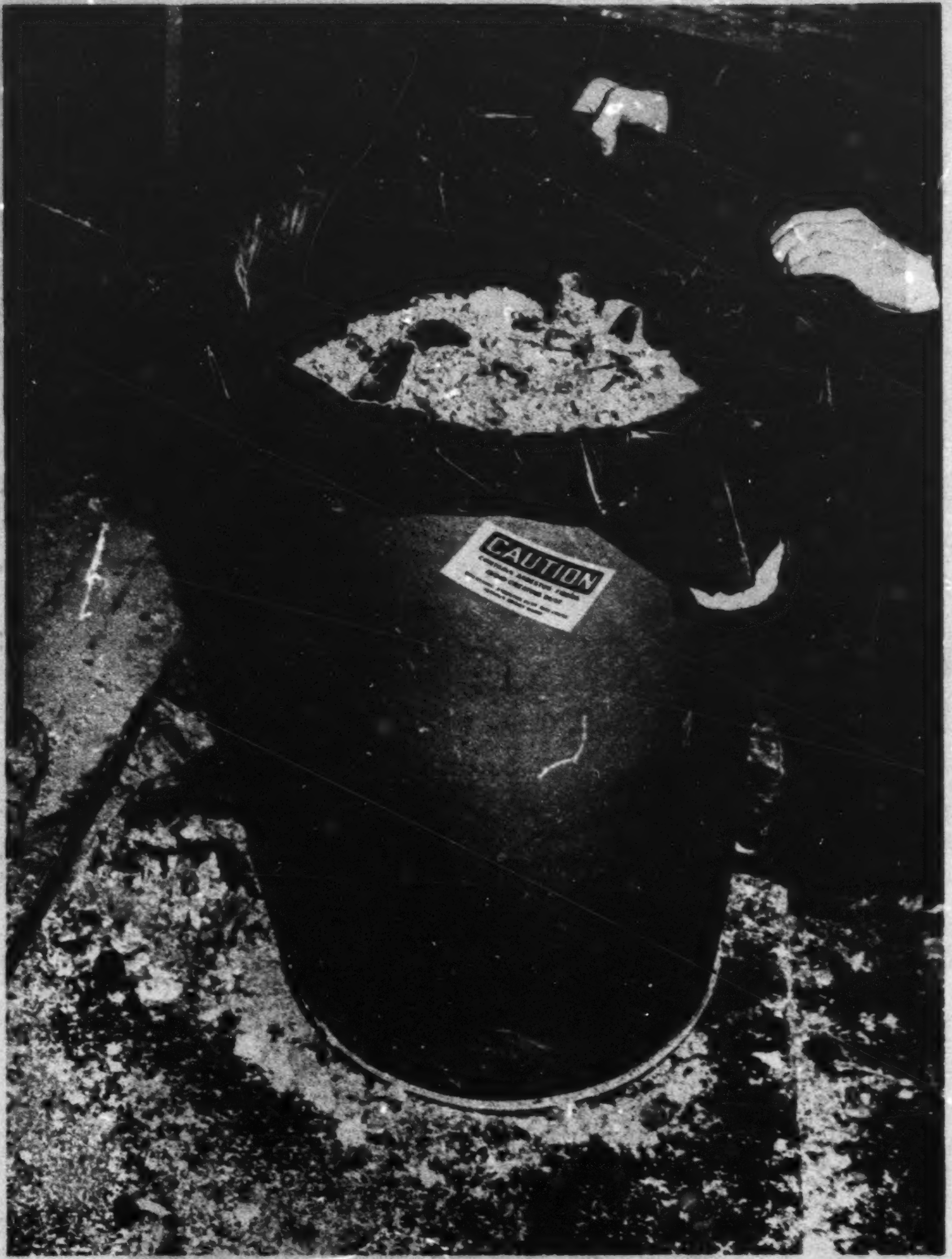


Figure E-2. Drum with 6-mil plastic liner to contain removed debris.

containment barriers and within the decontamination area should adequately determine the adequacy of contamination control. Air sampling will supplement post-removal visual inspections and establish the completeness of the removal process. Post-removal sampling during custodial activity is most likely to reveal residual contamination from settled fibers.

APPENDIX F
SUGGESTED SPECIFICATIONS FOR ASBESTOS REMOVAL

The following are suggested specifications which should be presented to a prospective contractor to determine whether a renovation or asbestos removal job can be accomplished in a safe and satisfactory manner.

1. Documentation of Performance in Asbestos Removal
   - a. The contractor shall furnish documentation of successful performance in asbestos removal. This will include name and address of purchaser of service, location of work performed, and a record or air monitoring for asbestos as required by OSHA 1910.1001.
   - b. The contractor will have at all times in his possession at his office (one copy) and in view at the job site (one copy), OSHA regulation 1910.1001, Asbestos, and Environmental Protection Agency 40 CFR Part 61, subpart B: National Emission standard for asbestos, asbestos stripping work practices, and disposal of asbestos waste.
2. Scope of Work
   - a. The contractor shall furnish all labor, materials, services, insurance and equipment necessary for the complete removal of all asbestos located at the site in accordance with the

guidelines or regulations of the responsible state agency, EPA and OSHA.

b. The contractor shall furnish proof that employees have had instruction on the dangers of asbestos exposure, on respirator use, decontamination, and OSHA regulations.

3. Worker's Dress and Equipment for Asbestos Removal

a. Work clothes will consist of full body coveralls, disposable head covers, boots, or sneakers, and respiratory protective equipment as required by OSHA regulations. Eye protection and hard hats should be available as appropriate.

b. Coveralls should be of a paper disposable type.

c. Respiratory protection for workers shall be provided by the contractor as required by current OSHA regulation.

3. Decontamination

All workers, without exception:

a. Will change work clothes at designated areas prior to start of day's work. Lockers or acceptable substitutes will be provided by the contractor for street and work clothes.

b. All work clothes will be removed in the work area prior to departure from this area. Workers would then proceed to showers. Workers will shower before lunch and at the end of each day's work. Hot water, towers, soap, and hygienic conditions are the responsibility of the contractor.

3. No smoking, eating or drinking is to take place once beyond the clean room at the job site. Prior to smoking, eating or drinking, workers will fully decontaminate by showering. Each worker will then dress into a new clean disposable coverall to east, smoke or drink. This new coverall can then be used to reenter the work area.

4. Work footwear will remain inside work area until completion of the job.

5. Pre-Asbestos Removal Preparation

   a. The contractor will thoroughly seal all openings and fixtures including, but not limited to, heating and ventilating ducts, sky lights, doors, windows, and lighting with polyethylene taped securely in place.

   b. Polyethylene sheets (6 mil minimum) will be used to cover the entire floor and wall surfaces.

   c. The contractor will set up a decontamination facility in a predesignated area which will house the changing room, shower area, and equipment area.

   d. Adequate toilet facilities should exist in the work area to avoid decontamination for this purpose. Where such facilities do not exist, the contractor will provide portable service.

   e. Procedures will be written for evacuation of injured workers. Aid for a seriously injured worker will not be delayed for reasons of decontamination.

6. Methods of Asbestos Removal

a. The asbestos material will be sprayed with water containing an additive to enhance penetration. The additive, or wetting agent, will be 50 percent polyethylene ester and 50 percent polyoxyethylene ether at a concentration of 1 ounce per 5 gallons of water. A fine spray of this solution must be applied to prevent fiber disturbance preceding the removal of the asbestos material. The asbestos will be sufficiently saturated to prevent emission of airborne fibers in excess of the exposure limits prescribed in the OSHA standards referenced in these specifications.

b. Removal of the asbestos material will be done in small sections with two-person teams, on staging platforms, if needed. The material will be packed into labeled 6-mil plastic bags held within 55-gal drums prior to starting the next section to prevent the material from drying.

c. Packed and sealed drums, with the required labeling, will be delivered to a predesignated disposal site for burial. Labels and all necessary signs shall be in accordance with EPA and OSHA standards.

d. Following removal, the entire area will be wet cleaned. After a 24-hour period to allow for dust settling, the entire area will be wet cleaned again. During this settling period, no entry, activity, or ventilation will be allowed. Twenty-four hours after the second cleaning all surfaces in the entire work area will be thoroughly vacuumed and wet mopped.

e. All polyethylene material, tape, cleaning material, and clothing will be placed in plastic-lined drums, sealed and labeled as described above for the asbestos waste material.

f. All equipment will be cleaned of asbestos material prior to leaving the work area.

7. Air Monitoring

a. Throughout the removal and cleaning operations, air sample monitoring will be conducted to ensure that the Contractor is complying with all codes, regulations and ordinances. The method to be used is described in OSHA standards, 1910.93a. The air monitoring technician and his equipment will be subject to approval of the purchaser's representative. Prior to the start of any work, the technician's method of measurement and proof that his method is approved by the Secretary of Labor of the United States will be submitted to the purchasers representatives for his approval.

b. Air monitoring will be performed to provide the following samples during the period of asbestos removal:

Area to be sampled	Number of samples	Minimum sample volume in liters
Work area	4	60
Outside work area barriers	2	120
Outside building	2	240

Samples will be taken after the actual removal operation has begun.

8. Clean-up and Guarantee

a. After the second cleaning operation the following test should be performed: A complete visual inspection should be made to insure dust free conditions, and two air samples within 48 hours after completion of all cleaning work should be taken. (Minimum volume of air sample 240 liters).

b. If noncompliance occurs, repeat cleaning and measurement until space is in compliance. Refer to 29 CFR 1910.1001, 7a.

9. Disposal of Asbestos Material and Related Debris

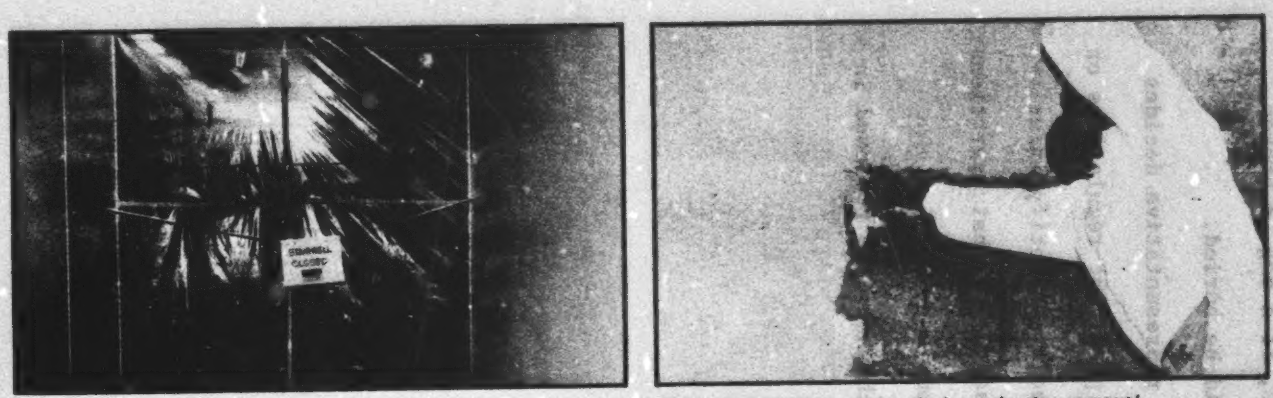
a. All asbestos materials and miscellaneous debris in sealed drums will be transported to the predesignated disposal site in accordance with the guidelines of the U.S. Environmental Protection Agency.

b. Workers unloading the sealed drums and machinery operators will wear respirators when handling material at the disposal site.

c. The bags may be dumped from the drums into the burial site. The drums may be reused. However, if a bag is broken or damaged, the entire drum should be buried.

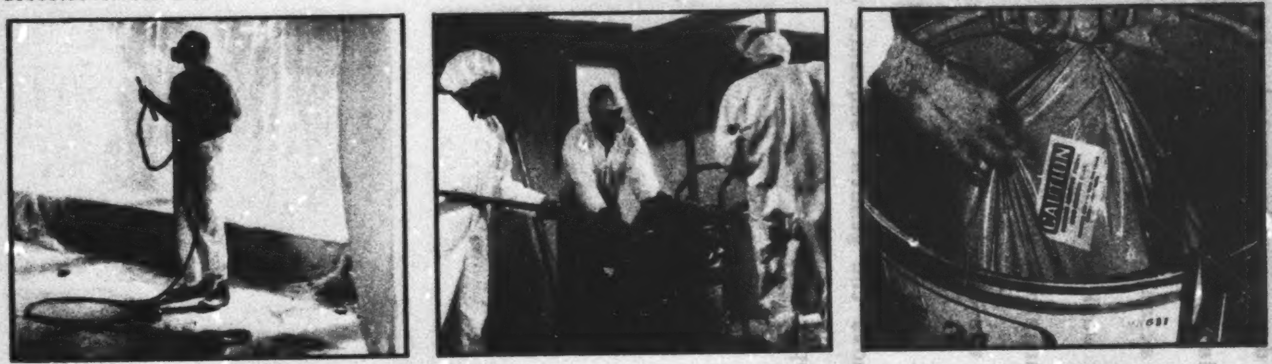
10. If, at any time, the purchaser's representative decides that work practice are violating pertinent regulations or endangering workers, he will immediately notify in writing the on-site contractor representative that operations will cease until corrective action is taken.

Figure F-1 shows the general sequence which should be followed in an asbestos removal operation.



Plastic barrier protects building occupants from the asbestos removal area.

Respirator protects worker during asbestos removal.



Ceiling asbestos wetted to decrease airborne fibers during removal process.

Asbestos material being loaded in approved containers.

Sealed bags are transported to sanitary landfill for disposal.

Figure F-1. Sequence of steps in an asbestos removal operation.

APPENDIX G

U.S. ENVIRONMENTAL PROTECTION AGENCY REGULATIONS PERTAINING TO ASBESTOS

The U.S. EPA Regulations contained in Title 40, Code of Federal Regulations, Part 61, as amended, applicable to asbestos removal operations are summarized below:

Subpart A - General Provisions

This subpart contains definitions (61.02), regional EPA office addresses (61.04), waiver information (61.10), (61.11) and other pertinent information.

Subpart B - National Emission Standard for Asbestos

Section	Content
§61.21 Definitions	Terms relating to asbestos material, visible emissions, demolition, friable asbestos material, renovation, wetting, removal, stripping, and waste material are defined in this section.
§61.22 Emission standard, work practice requirements	Contains information on application of standards, notification requirements, stripping of friable asbestos material, wetting, exhaust ventilation systems, restriction of spraying of asbestos containing material, waste

Section	Content
	material handling and labelling, and disposal regulations including site requirements.
	Specifies the applicability of standard to stripping or removal of asbestos materials of more than 80 meters (260 feet) of covered pipe, or 15 square meters (160 square feet) of friable asbestos materials used to cover a structural member.
	Written notification to Regional EPA Administrator is required 10 days prior to beginning of renovation (information to be provided is listed).
	Procedure to prevent emissions are described: adequate wetting, local exhaust ventilation systems, proper movement and handling, and exceptions to wetting requirements.
	Spraying of over 1 percent asbestos material on structural members is prohibited.
	Waste disposal methods in renovation shall not produce visible emissions: waste material will be placed in locktight container while wet, and disposed of in sites in accordance with provisions of §61.25

Section	Content
§61.25 Waste disposal sites	This section contains regulations on emissions access restrictions, sign posting, and operating methods for asbestos waste disposal sites.

Amendments to 40 CFR, Part 61 have been proposed and are found in the Federal Register of Wednesday, March 2, 1977. The proposed amendment will resolve certain ambiguities and omissions in the present standard.

The applicability of regulations on renovations, removing and stripping asbestos is broadened by deletion of phrases which limit application of the regulation to asbestos sprayed for insulation and fireproofing only. The proposed changes would enable the terms to cover all sprayed friable asbestos material, for whatever the intended purpose.

The amendment also clarifies the definition of structural member, and specifically includes nonload-supporting members such as ceilings and walls in the scope of the regulation.

2

APPENDIX H

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION REGULATIONS PERTAINING TO ASBESTOS

Applicable regulations of the Occupational Safety and Health Administration U.S. Department of Labor are contained in Title 29, Code of Federal Regulations, Part 1910. Regulations specific to asbestos removal or stripping are contained in Section 1910.1001 et seq. and are summarized below:

Section 1910.1001	Content
(a) Lists definitions.	Definitions of asbestos and asbestos fibers, size limitation of 5 micrometers or longer.
(b) Sets limits for permissible exposure to airborne concentrations of asbestos fibers.	Eight-hour time-weighted average TWA: two fibers, longer than 5 micrometers, per cubic centimeter of air (f/cm^3). Maximum concentrations: 10 f/cm^3.
(c) Methods of compliance recommend methods to meet limits for exposure.	(1) Engineering methods: isolation, enclosure, ventilation, dust collection should be used to meet the exposure limits.

Section 1910.1001	Content
	(2) Worker protection: Wet methods will be used, insofar as practicable, to prevent the emission of fibers in excess of the limits. (2)(iii) This section lists specific requirements for both respiratory protection and special clothing for removal workers.
(d) Personal protective equipment is specified for various conditions.	Respiratory protective equipment and special clothing are required whenever the exposure limits can reasonably be expected to be exceeded. Equipment approved by the agency is referenced. Respiratory protection: (d)(2)(i) Concentrations up to 10 times the allowable limit (20 f/cm^3 TWA, or 100 f/cm^3 ceiling limit): air purifying respirator. (d)(2)(ii) Concentrations up to 100 times the limit (200 f/cm^3 TWA, or 1000 f/cm^3 ceiling limits) require powered air purifying respirator. (d)(2)(iii) Concentrations above 100 times the limit require type "C"

Section 1910.1001	Content
	supplied air respirator, continuous flow or pressure demand class. (d)(3) Special clothing shall be provided if limits are exceeded. Includes coveralls, head coverings, foot coverings. When clothing requirement is met, laundering service or disposal should be provided.
(e) Method of measurement of fiber concentrations is defined.	Determinations of airborne concentrations of asbestos fibers shall be made by the membrane filter collection method with phase contrast microscopy.
(f) Specific procedures of measurement and monitoring.	Personnel monitoring, environmental monitoring and frequency of monitoring are covered.
(g) Caution signs and labels are defined.	Specifications and use of signs are outlined. Posting of work sites and use of caution labels on asbestos material are described.
(h) Housekeeping to reduce exposure and waste disposal methods are described.	Cleaning of all objects of accumulated asbestos debris, and sealing in impermeable, sealed containers.

Section 1910.1001	Content
(i) Specifies recordkeeping and requirements for maintenance and retention of records.	Employer records on exposure. Time requirements and record disposition are covered. Records of monitoring should be retained for 3 years.
(j) Lists medical examination requirements.	Applicability, specific requirements, frequency of medical evaluations. Annual and termination examination requirements are listed.

A notice of proposed of rule-making for occupational exposure to asbestos (29 DFT Part 1910) is found in the Federal Register, Thursday, October 9, 1975. The major issues relevant to removal and stripping operations contained in this proposal are:

1. Lowering of the exposure limits to 0.5 f/cm^3 TWA and lowering of the ceiling limit to 5 f/cm^3. Ceiling concentration sampling time is defined as a period up to 15 minutes.
2. The applicability of the standards to transient work forces, such as those found in demolition and removal is discussed. This reflects a concern for exposures in work places of a non-fixed nature, and resolves the ambiguities in this area.
3. No one type of respiratory protection is required in removal or stripping activities, but is in proportion to anticipated concentrations of asbestos.
4. The regulated area concept is introduced as any work area where a person may be exposed to airborne concentrations of asbestos fibers in excess of the limits imposed.

5. Decontamination by showering is required.

6. An employee information and training program is required.

A revised recommended asbestos standard was promulgated by NIOSH in December 1976. The recommended exposure level in this document is 0.1 f/cm^3 8-hour TWA with ceiling concentrations not to exceed 0/5 f/cm^3 based on a 15-minute sample. The essential purpose of this reduction is to materially reduce the risk of asbestos-induced cancer. The analytical technique of phase contrast microscopy is retained in this recommended standard.

APPENDIX I

U.S. ENVIRONMENTAL PROTECTION AGENCY AND OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

EPA REGIONAL OFFICES

Region I
Connecticut, Maine, Massachusetts,
New Hampshire, Rhode Island and
Vermont
John F. Kennedy Federal Building
Room 2303
Boston, Massachusetts 02203
(617) 223-7210

Region II
New York, New Jersey, Puerto Rico,
Virgin Islands, and Canal Zone
Federal Office Building
26 Federal Plaza
New York, New York 10007
(212) 264-2525

Region III
Delaware, District of Columbia,
Maryland, Pennsylvania, Virginia,
and West Virginia
Curtis Building
Sixth and Walnut Streets
Philadelphia, Pennsylvania 19106
(215) 597-9814

Region IV
Alabama, Florida, Georgia, Kentucky,
Mississippi, North Carolina, South
Carolina, and Tennessee
345 Courtland St., NE
Atlanta, Georgia 30308
(404) 881-4727

Region V
Illinois, Indiana, Minnesota, Michigan, Ohio, and Wisconsin
230 South Dearborn
Chicago, Illinois 60604
(312) 353-2000

Region VI
Arkansas, Louisiana, New Mexico,
Oklahoma, and Texas
First International Building
1201 Elm Street
Dallas, Texas 75270
(214) 749-1962

Region VII
Iowa, Kansas, Missouri, and Nebraska
1735 Baltimore Avenue
Kansas City, Missouri 64108
(816) 374-5493

Region VIII
Colorado, Montana, North Dakota,
South Dakota, Utah, and Wyoming
1860 Lincoln Street
Denver, Colorado 80295
(303) 837-3895

Region IX
Arizona, California, Hawaii, Nevada,
Guam, American Samoa, Trust Territory
of the Pacific
100 California Street
San Francisco, California 94111
(415) 556-2320

Region X
Alaska, Idaho, Oregon, Washington
1200 Sixth Avenue
Seattle, Washington 98101
(206) 442-1220

DEPARTMENT OF LABOR
OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

REGIONAL OFFICES[a]

Region I
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont
John F. Kennedy Federal Building
Government Center
Room 1804
Boston, Massachusetts 02203
(617) 223-6712/3

Region II
New York, New Jersey, Puerto Rico, Virgin Islands, and Canal Zone
1515 Broadway
(1 Astor Plaza)
Room 3445
New York, New York 10036
(212) 399-5941

Region III
Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia
Suite 2100
Gateway Building
3535 Market Street
Philadelphia, Pennsylvania 19104
(215) 596-1201

Region IV
Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee
Suite 587
1375 Peachtree St., NE
Atlanta, Georgia 30309
(404) 881-3573

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[a] The regional offices should be contacted to find the area office nearest you.

Region V
Illinois, Indiana, Minnesota, Michigan, Ohio, and Wisconsin
Room 3263
230 S. Dearborn Street
Chicago, Illinois 60604
(312) 353-4716/7

Region VI
Arkansas, Louisiana, New Mexico, Oklahoma, and Texas
Room 602
555 Griffin Square Building
Dallas, Texas 75202
(214) 749-2477

Region VII
Iowa, Kansas, Missouri, and Nebraska
Room 3000
911 Walnut Street
Kansas City, Mo. 64106
(816) 374-5861

Region VIII
Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming
Room 15010
Federal Building
1961 Stout Street
Denver, Colorado 80294
(303) 387-3883

Region IX
Arizona, California, Hawaii, Nevada, Guam, American Samoa, and
Trust Territory of the Pacific
P.O. Box 36017
9470 Federal Building
450 Golden Gate Ave.
San Francisco, California 94102
(415) 556-0586

Region X
Alaska, Idaho, Oregon, and Washington
Room 6048
Federal Office Building
909 First Avenue
Seattle, Washington 98174
(206) 442-5930

APPENDIX J

COMMERCIAL SOURCES OF MATERIALS, AND EQUIPMENT FOR ASBESTOS REMOVAL OPERATIONS

AIR SAMPLING PUMPS

1. Bendix
   Environmental Science Division
   1400 Taylor Avenue
   Baltimore, Maryland 21204

2. Millipore Corporation
   Bedford, Massachusetts 01730

3. Mine Safety Appliance Company
   201 North Braddock Avenue
   Pittsburg, Pennsylvania 15208

4. National Environmental Instruments, Inc.
   P.O. Box 590
   Warwick, Rhode Island 02888

5. Willson Products Division
   ESB Incorporated
   P.O. Box 622
   Reading, Pennsylvania 19603

VACUUMS: INDUSTRIAL HEPA FILTERED

1. American Cleaning Equipment Corporation
   111 South Route 53
   Addison, Illinois 60101

2. NILFISK of America, Inc.
   P.O. Box 713
   201 King Manor Drive
   King of Prussia, Pennsylvania 19406

Note: It is recognized that equipment and services other than those cited in this report may be available. Mention of company or product names is not to be considered an endorsement by the authors.